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**Constructing scientific knowledge in the classroom: a multimodal analysis of  
conceptual change and the significance of gesture**

**Thesis submitted for the Degree of  
Doctor of Philosophy  
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**by**

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## Abstract

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Constructivism remains one of the most influential views of understanding how children learn science today. Research investigating learning from within this viewpoint has led to the development of a range of theoretical models, most of which aim to explain the underlying processes associated with conceptual change. Such models range in depth and scope with some attributing change to purely cognitive processes while others suggest a role for social factors. Contemporary research has also begun to explore links between the role of practical activity, skills development and language. This study utilises a cross-sectional design in order to investigate the development of children's ideas and concepts related to two areas of the English National Curriculum for Science: 'electricity' and 'floating and sinking'.

A new and innovative multimodal methodology combining practical science activities and traditional / conventional perspectives alongside interview and observational protocols is presented. Multimodal research proposes that knowledge and meaning are transmitted through a range of responses types including language, drawings and gesture. The participants in this study were children aged 7, 11 and 14 years attending four schools in the East Midlands region. Results demonstrate that the children's ideas could be developed using conceptual challenge tasks. The gestures that the children produced were categorised according to five different forms: referential, representative, expressive, thinking and social, often containing information about their science ideas that was not included in other response types. The results also begin to uncover how meaning is socially constructed and supported. These results form the basis of a critique of methodology intended to re-evaluate and inform debate arising from different models of conceptual change. The potential importance of studying children's gestures in classroom settings for providing important cues and clues to underlying thoughts that may not be present in verbal or other more conventional responses alone is highlighted.

**Keywords:** Learning in science, constructivism, conceptual change, multimodal research, gesture analysis

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# Chapter 1 Introduction

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## 1.1 Background

The research presented in this thesis explores how children's ideas in science change, from both traditional and multimodal perspectives. The multimodal perspective suggests that communication occurs across a range of response types (Kress, et al., 2001a, Jewitt, et al., 2001). These response types include drawings, verbal and written communication, and non-verbal communication such as body language and gesture (Kress, et al., 2001). The multimodal approach to understanding how knowledge is portrayed and discussed is still a new and evolving field of research. However, the approach has been applied in research investigating how science is communicated by teachers in the classroom (Kress, et al., 2001), how children use multimodal resources when discussing their ideas (Taylor, 2006; Blown & Bryce, 2010, Padalkar & Ramadas, 2011, Tang, et al., 2011), and how different response types can add further understanding to the ideas that children hold (Crowder & Newman, 1993; Goldin-Meadow, 1997, 2000, 2003; Crowder, 1996). As yet, this approach has not been used to detail the notion of 'conceptual change', a full definition of which is provided in a subsequent section of this introduction. This work addresses this gap by attending to an analysis of gesture, establishing a typology of gestures that children use and what, if anything, this can reveal about children's underlying ideas. Specifically, this work explores how children's ideas about electricity and floating and sinking change both within and across primary and secondary school age phases, whether or not such changes can be instigated through a 'conceptual challenge' approach when teaching, and what, if anything, the analysis of gesture in conjunction with analysis of other response types might add to conceptual change theories.

As with all research it is important to position the researcher in relation to the project that will be discussed in this work. The researcher has a background in psychology, and has been responsible for teaching psychology for some time. The researcher

has a deep interest in the processes of education, the way that learning occurs, and the learning strategies that children use when developing their ideas in the classroom. This interest has been evident since first training at undergraduate level when the researcher considered a career teaching primary aged children. Prior to undertaking the work detailed in this thesis, the researcher had worked in a number of primary schools on a voluntary capacity and had held an administrative role. The researcher had already undertaken educational research with primary aged children and university students and was seeking to extend this experience at secondary level. During the work undertaken for this thesis, the researcher volunteered in a local secondary school where, working alongside the special needs tutor, an after school science club was held once a week. The science club was open to all of the children from Year 7 onwards and often the children in attendance were there because of their interest in science. Previous experiences and the role within the science club was fundamental to supporting the researcher to develop effective approaches to working across all levels and provided valuable insight into the children's ideas across a range of topics not just those detailed within this thesis. Philosophically, the researcher adopted a pragmatic approach to research, whereby the methods and analytical frameworks utilised were selected on the basis that they would enable the effective investigation of the research questions explored. Meeting the research aims included developing effective analytical procedures in order to explore the different responses types detailed previously. A further discussion of these analytical procedures is offered later.

In this chapter, the general background to the work undertaken is outlined. The constructivist view of learning and the importance of the conceptual change movement in science education research is introduced and reviewed. A concise overview of both the traditional / conventional aspects to this work and its original features are highlighted.

## **1.2 Science in the National Curriculum**

Understanding children's learning in science is important intrinsically and because science has played a fundamental role within the English education system, particularly since the appearance of a National Curriculum of subjects in 1989. At this time, science along with English and mathematics formed the core components of a centralised educational agenda intended to improve standards. Electricity and floating and sinking have been included in the science component since its inception. In the contemporary curriculum these two science areas appear within Physical Process and Materials and their Properties. Both areas are also taught, although to varying degrees, through all four of the Key Stages (DfEE & QCA, 1999). Both science areas are concept rich and practical in nature and both had already been encountered previously by the children prior to participation in the research. However, despite the original commitment directed to science, subsequent developments and changes to the guidance associated with the science curriculum have led to questions over its provision particularly in the primary sector (Sharp & Grace, 2004).

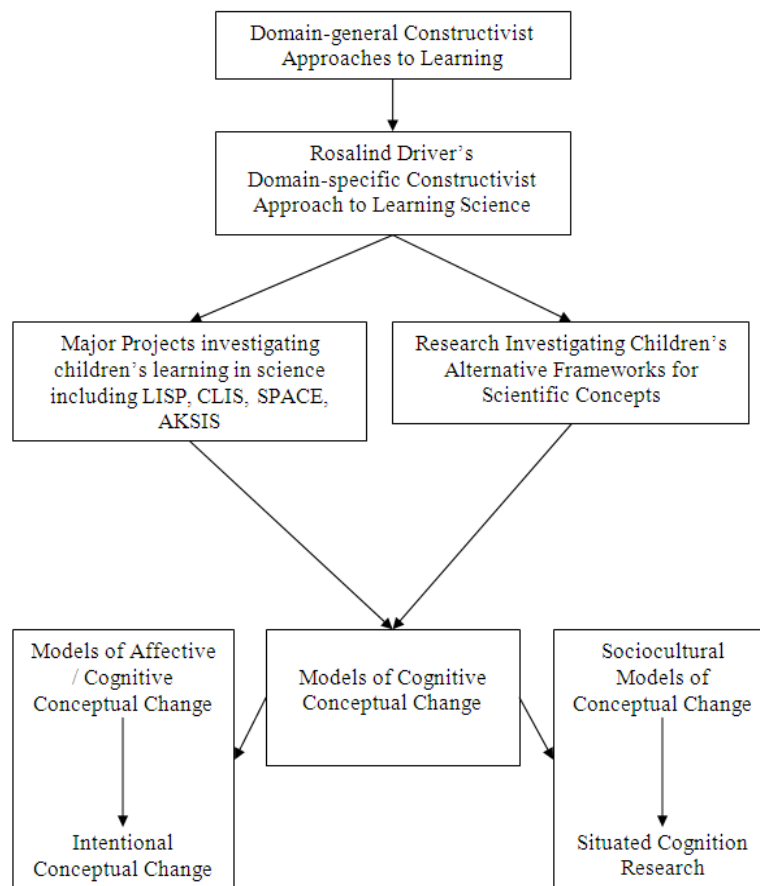
There has, of course, been much criticism of the National Curriculum (Sharp et al, 2011), and it has been suggested that despite its initial impact resulting in educational achievement (Fortune, et al., 1993; HCEC, 1995; Ofsted, 2002) many teachers struggled to meet the demands of this subject (Boyle & Bragg, 2005; Ofsted, 2008; Ritchie, 1996; Russell, et al., 1995). Although there have been attempts to improve the skills of teachers in delivering the science curriculum this domain remains problematic and difficult (Jarvis, et al., 2003, Kinder & Harland, 1991, Kruger, et al., 1994). Many teachers have limited subject knowledge in science and also have little confidence for teaching this area particularly at primary level (Holroyd & Harlen, 1996; Osborne & Simon, 1996; Russell, et al., 1992). Negative perceptions and attitudes have also been detected (Abd-El-Khalick & Lederman, 2000, Lunn, 2002, Parker & Spink, 1997, Pell & Jarvis, 2003; Waters-Adams, 2006). More recent political events resulting in uncertainty regarding the status and direction of science within the National Curriculum make it difficult to describe the contemporary context fully. However, what is clear is that science remains an important, yet often overlooked, subject in the curriculum and may form the

foundation of many subsequent career paths for children. Despite the political uncertainty, some recent publications still maintain that the knowledge that children gain during science education offers a valuable approach to thinking that promotes other areas of educational attainment and the development of essential life skills (The Royal Society, 2010).

### **1.3 Children Learning Science**

Children learn science in two distinct ways. Firstly, science learning is characterised as taking place through the development of practical and intellectual skills (Levinson, 1994; Millar & Osborne, 1998). Secondly, science learning is defined as taking place through knowledge acquisition and concept learning (Driver, et al., 1985). It is from these skills, knowledge and concepts that children's ideas in science emerge. The assertions made in most recent documents support and justify the continued need for well-developed studies that aim to provide insight into the learning mechanisms that underpin skills development and the development of children's ideas (Vosniadou, 2008).

Over the last 40 years, there has been a diverse and extensive body of research that has aimed to investigate the ways that children learn science and the factors that influence this learning. A summary of different directions is presented in Figure 1. As can be seen, contemporary views of children's learning in science have their roots in the global constructivist approaches to learning. These approaches are derived from important theorists such as Piaget (1929, 1974) and Vygotsky (1978), both of whom played active roles in establishing constructivism in Europe. During the period of time that these authors were establishing a constructivist view in Europe a North American stream of research was also being developed. The North American theorists included Kelly (1955), Bruner (1966), Gagné (1975, 1985), and Ausubel (1968, 1978). All of these important theorists continued the development of constructivist views of learning by incorporating their results into research in behaviourism, cognitive science, and education.



*Figure 1: 'Roadmap' of the development of UK research investigating children's ideas in science from a constructivist perspective and the resulting lines of experimental research designed to uncover the learning processes.*

These important global constructivist views introduced were later encapsulated in the domain-specific approach to constructivism for science education developed by Driver (1983, 1985, 1994). Driver was a prolific researcher and writer and spearheaded the dissemination and importance of the constructivist view in science education and science education research. Importantly, Driver took the different constructivist perspectives presented earlier and developed them into a coherent body of work that explained teachers' experiences of children's classroom learning, for example, that children came to class with existing ideas in science, that these ideas were subject to change through tuition and that even though children might have changed their ideas they may not believe them (Driver & Bell, 1986). Driver's work was so fundamental that it gave rise to an enormous body of research which is now known as the Alternative Conceptions Movement (Taber, 2006). The Alternative

Conceptions Movement is highlighted in Figure 1 by the major science education research projects presented. These important research projects were fundamental for successfully helping to raise the profile of science education and for developing different pedagogical approaches to support tuition (e.g. Scott, et al., 1987). These projects also led to the development of various models which aimed to map how children's ideas changed (West & Pines, 1985; Limon & Mason, 2002; Vosniadou, 2008). In the first instance such changes were mapped according to the cognitive processes that supported such development (West & Pines, 1985, Limon & Mason, 2002, Vosniadou, 2008). In Figure 1 it can be seen that these models of cognitive conceptual change also resulted in two other parallel research strands. The first of these was highlighted within a 'warming' trend where researchers began to explore the importance of affective aspects such as motivation (Pintrich, et al., 1993; Sinatra & Pintrich, 2003; Sinatra, 2005). This strand became known as 'Intentional Conceptual Change'. The second strand began to explore sociocultural aspects such as learning environment of the child and became known embedded within 'Situated Cognition Research' (Vosniadou, 2007). Cognitive conceptual change is still a prominent research field. So much so that a recent handbook on conceptual change has been published (Vosniadou, 2008). However, constructivism and conceptual change research is not without its criticism. For example, Phillips (1995) proposed that there were so many forms of constructivism that it was difficult to tell which was being applied at any time. Taber (2010) furthered such criticism and proposed that the application of constructivism was problematic. These criticisms are important and will be developed further in Chapter 3. However, it is proposed that despite the critiques constructivism and cognitive conceptual change remains influential in science education research and it is in this field that this project is grounded. The social aspects of learning are also explored.

What is clear, and with reference to Figure 1, is that the body of science education research stands as a testament to the enormously powerful premises of the constructivist approach to learning, which have been adopted in the field of science education in a manner that is perhaps not evident in any other school subject discipline. The powerful adoption of the constructivist approach may have occurred for two reasons: firstly because the children often have had first-hand experience of the phenomena that they formally study in the curriculum long before they ever enter



into a formal educational environment; secondly, the analogy between constructivism and working practices of a scientist who is actively constructing new understanding resonates coherently with teachers who are working with children in the classroom and attempting to recreate those moments of epiphany when new scientific discoveries are made in order to extend and support children's learning. Indeed in almost all science classrooms the use of practical demonstrations in order to illustrate scientific concepts is considered to be critical for effective science teaching (Gott & Duggan, 1996; Wellington, 1998; Wickman & Ostman, 2002; Hogarth, et al., 2005; Millar, 2010). Notably, it is because of the pre-existing knowledge that the children hold that science teaching is often faced with the task of either changing children's perceptions of these experiences so that they are coherent with the established body of scientific knowledge that it is anticipated that children will learn or extending children's understanding to include complex scientific terms and advanced ideas and concepts (Driver, et al., 1985).

The processes of change that children's ideas and concepts undergo during their education have been extensively studied in the conceptual change research and although there are many different ways of understanding conceptual change there is general agreement that part of a child's education in science involves the process of restructuring ideas and concepts until they become more representative of scientific views (Vosniadou, 2008). What is less clear, however, are the actual processes that are undertaken when ideas and concepts are developed and changed. Today this area is still an active research strand. As indicated earlier, other research in science education has, however, begun to highlight that multimodality may be important both in terms of understanding teaching and in terms of understanding what and how children learn (Kress, et al., 2001). Studies have begun to demonstrate that teachers use a range of representations, both verbal and non-verbal, when they are teaching science (Kress, et al., 2001). Text books, drawings and pictures, models and gestures have all been shown to play a valuable role in representing many science concepts and are frequently employed by science teachers in order to increase children's understanding. Complementary studies have shown that children also use a range of response types when discussing their knowledge (Crowder & Newman, 1993; Crowder, 1996; Goldin-Meadows, 2000; Roth & Lawless, 2002). This multimodal research strand proposes that each form of response type may contain

its own affordances which permit the demonstration of different aspects of knowledge and although still in its infancy it is beginning to highlight many potential areas for study (Kress, et al., 2001). This work therefore aims to build on these existing foundations to incorporate a multimodal approach into a more conventional conceptual change research framework.

## **1.4 About This Study**

This current work aims to build on the constructivist (Driver, 1985; Steffe & Gale, 1995) and conceptual change literature (Vosniadou, 2008) and extend the way that the development of children's ideas is understood by introducing a new and somewhat innovative multimodal approach to studying the development of children's ideas in science (Jewitt, 2011). Emerging literature has identified that children, especially those of primary age, may struggle with the complexity of scientific language but may nevertheless hold advanced ideas for certain science concepts (Roth & Lawless, 2002). The language barriers that children encounter when discussing ideas with teachers and other adults may result in misconceptions being diagnosed even when these may not exist (Ausubel, 1968, 1978). Importantly, the same research has begun to identify that there may be other clues and cues to the more complex underlying ideas that children hold which are not expressed in language. For example, evidence may be drawn from children's drawings, gestures and approaches to tasks as these may contain representations that can be used in the interpretation of their ideas (Crowder & Newman, 1993; Goldin-Meadows, 2000). This work explores these multifaceted response types during practical science activities in order to determine if it is possible to use a multimodal approach to study knowledge acquisition and concept learning and to explore whether this can add to what is already known.

As indicated, the work presented here focuses on two science areas: electricity and floating and sinking (the Archimedes Principle). These two contrasting topics were explicitly chosen in order to provide a basis for comparisons. Both had been previously studied in the conceptual change literature (e.g. for electricity, Shipstone, 1985; Osborne, et al., 1991; Borges & Gilbert, 1999, for floating and sinking, Inhelder

& Piaget, 1958; Howe, et al., 1990; Havu-Nuutinen, 2005). Electricity as taught in school is often conceptually driven and counter-intuitive and relies on children's abilities to interpret phenomena that are not always directly observable. Floating and sinking, on the other hand, was chosen as this provides children with the opportunity to explore a topic that they may have encountered many times before in a concrete way with resources that could be directly manipulated. The participating children for the main phase of study were selected from three age groups: Year 2 (6-7 years of age; N = 34), Year 6 (11-12 years of age; N = 44) and Year 9 (13-14 years of age; N = 15). These age groups were chosen because they represent the end of the Key Stages 1 -3 in the English school system and thus provide insight into school-based transition stages in children's development. However, as the Year 9 children were just beginning their GCSE level studies at the time that the research was undertaken it was more difficult to recruit for this age group and this is reflected in the lower sample size. The sample for the main phase of study was drawn from one mainstream primary school, one independent school and one secondary school. These schools were considered to be typical of the local geographic area and thus are proposed to be largely representative of at least the local population.

As previously discussed, this work builds on cognitive conceptual change research in order to explore in more depth the changes that are evident in the topics of electricity and floating and sinking between primary and secondary aged children. As a point of departure from previous studies, a multimodal approach to studying the development of children's ideas is adopted which aims to deliberately challenge the existing ideas that children have using practical science activities. Furthermore, a specific methodological approach was developed for this study that combines different approaches. Notably, the work adopts a dialogic approach (Alexander, 2004; Fisher, 2007; Mercer, et al., 2009; Haneda & Wells, 2010) in order to establish effective interview protocols, a collaborative learning setting (Howe, 2009) in order to bring the research environment as close to normal classroom practice as possible, and uses observation and focus group techniques. It was established that by audio / video recording the activities the researcher would be able to analyse in depth the range of response types that the children used and if changes in cognitive structure arose from these events it was hoped that it would be possible to capture these changes as they occurred, thus providing a critical insight into the conceptual change

mechanisms that operate. Specifically this work will investigate the following research questions:

- does a multimodal analysis of verbal and non-verbal communication facilitate a better understanding of children's ideas in science?
- can such analyses be utilised in order to explore and contribute to an understanding of the dynamics of conceptual change?
- do outcomes from the work in this thesis have any classroom application?

These research questions do perhaps also propose an overarching question regarding whether or not it is possible to apply a multimodal research lens to the issue of conceptual change in science education.

## **1.5 Originality**

Originality in this thesis can be evidenced at many levels. First and foremost is the multimodal, task-based approach which was developed specifically for this work and which aimed to provide children with the opportunity to use and portray gestures, drawings and interpersonal aspects of their knowledge. As introduced in the previous section and discussed in further detail in Chapter 5, this approach incorporates interviews, focus groups and observation protocols in order to elicit and explore children's ideas. The researcher also used a dialogic approach (Mercer, et al., 2009) and the children participated in collaborative learning (Howe, 2009) which enabled the research to accurately reflect a typical classroom learning environment. All elicitation was based on responses received during practical science activities. Children's participation in the science activities was audio / video recorded in order to permit a detailed analysis of the different response types. As the study itself generated large volumes of data (approximately 72 hours of video data alone) a number of approaches were adopted or developed to reduce the data and to manage the analysis. An NVivo project was designed in order to track the coding of arising themes across the different age groups and in order to explore the responses for individual children within the project. Whilst this enabled the effective

management of data, an analytical framework which permitted the evaluation of the underlying meaning of the different response types was developed and assessed. In particular an emphasis was placed on the analyses and interpretation of the gestures that the children produced as these were proposed to have provided a route of communication for the children who may have struggled to articulate their ideas verbally. Indeed, the analysis of the children's gestures provided an opportunity to construct the different categories of gestures that the children used and subsequently this provided the first opportunity to generate categories of gesture that could be specifically relevant for the science topics of electricity and floating and sinking. In order to present the results two new approaches were developed and trialled. The first of these was 'storyboarding'. Storyboarding, which has been traditionally used in business and more predominately in media production, was introduced to provide one effective measure through which the range of response types displayed could be presented and monitored across the duration of the science activities. In order to explore the changes in concepts that occurred over time during the activities, a timeline analysis for the ideas that children discussed was further developed from work by Givry and Tiberghien (2012). The timeline analysis offered valuable insight into the processes of conceptual change that might be evident during a single teaching event. These are discussed in more depth in the later chapters of this work.

## **1.6 Chapter Summaries**

In order to add to assist readers in their navigation of this thesis an overview of subsequent chapters follows.

Chapter 2 – The Emergence of Constructivism: Global Perspectives – this chapter details what a constructivist view of learning in science is (Steffe & Gale, 1995) and presents the more common global theories of constructivism including those from the European school such as Piaget (1929, 1974) and Vygotsky (1978) and those from the North American school such as Kelly (1955), Bruner (1966), Gagné (1975) and Ausubel (1968). All of these key theorists had an important impact on the development of a domain specific view of constructivism as is used in contemporary

science education today. Whilst the importance of detailing these views might be questioned, it is proposed that understanding their philosophical insights and their research basis can provide important background that helps the reader to appreciate the context of this work. This background chapter provides a comparative analysis of these key constructivist thinkers and begins to critique the constructivist view adopted.

Chapter 3 – Contemporary Constructivism: A Domain-Specific Perspective – this chapter discusses the evolution of a domain-specific constructivist view of science learning. Fundamentally, it is in this chapter that Driver's extensive and influential work is introduced (e.g. Driver & Easley, 1978; Driver, 1985, 1995). The chapter explores some of the important science education research programmes (e.g. the Children's Learning in Science Project and The Science Processes and Concept Exploration Project), the importance of which is highlighted before turning to a discussion of the research literature that has explored the areas of electricity (e.g. Shipstone, 1985; Osborne, et al., 1991; Borges & Gilbert, 1999) and floating and sinking (e.g. Inhelder & Piaget, 1958; Howe, et al., 1990; Havu-Nuutinen, 2005). Subsequently, the view of learning as cognitive conceptual change (Vosniadou, 2008) is introduced and a selection of the different models of conceptual change that have been developed in order to explain how children's ideas change over time are reviewed (Vosniadou & Brewer, 1987; diSessa, 1988; Karmiloff-Smith, 1992; Luffiego, et al., 1994). These models of change are evaluated for their utility. The chapter ends by introducing the point of departure for this work compared to previous conceptual change projects.

Chapter 4 – Methodology 1: Overall Design and Other Considerations – this chapter introduces the overall design of this research project including the two science areas explored using the dialogic teaching approach developed (Alexander, 2004; Mercer, et al., 2009) and the ways that the children's responses were measured. The importance of method is highlighted and critiqued using typical approaches for studying conceptual change. The chapter then explores the context of the current study and discusses the pilot studies undertaken and the way that these have helped to develop the project overall. This chapter concludes with a critique of research

which aims to interpret the ideas of children using a framework proposed by Johnson and Gott (1996).

Chapter 5 – Methodology 2: The Development of a Multimodal, Task-based Approach – this chapter discusses the importance of the underpinning theoretical frameworks used in this work and the ideas related to multimodality are discussed in relation to the findings from the pilot studies. Important studies from authors such as Kress (et al., 2001), Jewitt (2011) and Roth and Lawless (2002) are discussed. This chapter then details the development of a typology of gestures used in science activities (Callinan & Sharp, 2011). The results of the pilot study highlight the importance of studying gesture and including these details in future work. Next, the chapter turns to a discussion of the development of a storyboarding approach to investigating children's ideas in science. This particular approach is a fundamental component of the originality contained within this work. Next, in order to highlight how changes in ideas can be mapped during a single activity, the development of a timeline analysis which aims to build on the work of Givry and Tiberghien (2012) is discussed.

Chapter 6 – Children's Ideas about Electricity: A Multimodal Perspective – this chapter presents the results of the electricity activities. These results are discussed in both conventional and multimodal terms. The differences between age groups is used in order to highlight the ways that ideas are proposed to change over time. The differences within the groups as measured at the beginning and end of the activities is discussed in order to show how, if at all, ideas changed within the context of a single activity. In order to explore the potential impact of the multimodal approach and what this adds to our understanding of children's ideas, an analysis of the types of gestures that children used during their discussion of electricity is presented. Subsequently, three group studies exploring the impact of the different response types are used to illustrate how children used different resources in order to express their ideas. Finally, a timeline analysis of the Year 9 group study is used to highlight how children's ideas change during the course of the activities.

Chapter 7 – Children's Ideas about Floating and Sinking: A Multimodal Perspective – this chapter presents the results of the floating and sinking activities. These results

are discussed in both conventional and multimodal terms. The differences between age groups is used in order to highlight the ways that ideas are proposed to change over time. The differences within the groups as measured at the beginning and end of the activities is discussed in order to show how, if at all, ideas changed within the context of a single activity. In order to explore the potential impact of the multimodal approach and what this adds to our understanding of children's ideas, an analysis of the types of gestures that children used during their discussion of floating and sinking is presented. Subsequently, three group studies exploring the impact of the different responses types are used to illustrate how children use different resources in order to express their ideas. Finally a timeline analysis of the Year 6 group study is used to highlight how children's ideas change during the course of the activities.

Chapter 8 – Discussion and Conclusions – this chapter discusses the overall results of the project. The discussion returns to the research questions detailed in Section 1.4 and proposes how the research undertaken in this thesis has responded to these. As with all previous chapters, the discussion responds to a traditional approach before turning to a critical review of the multimodal aspects. The resulting discussion then addresses any recommendations that can be drawn from the work in this thesis and relates this to classroom practice, assessment and curriculum development before making a number of recommendations for further multimodal research in science education.

## **1.7 Discussion**

In this chapter the broad aims of this work have been introduced. The underpinning constructivist view of science education proposed by Driver (1985, 1995) was used to provide a foundation for an original study that explores the way that children's ideas about electricity and floating and sinking develop and change over time. This work uses the responses from three age groups of children (in Year 2, Year 6, and Year 9), the age groups representing transitional phases between the Key Stages in the English education system, and aims to develop a new approach to studying these ideas by using a multimodal, task-based approach. The multimodal, task based approach is grounded in a dialogic teaching approach (Mercer, et al., 2009)



and also utilises collaborative group work (Howe, et al., 2009) and practical science activities. Fundamental to the work is the intention to match the typical learning environments of the children as closely as possible so that the results of the work may have high levels of ecological validity. The sessions aim to deliberately challenge the ideas that the children hold in order to explore what, if any, changes occur as a result of teaching. The results of the subsequent analyses will then be related to models of cognitive conceptual change presented in detail in Chapter 3. In order to explore the data from a multimodal perspective, this work also develops two new approaches to analysis. The first is storyboarding. The storyboards aim to highlight the different response types (e.g. drawing, written, verbal and gesture) that the children use when discussing their ideas as well as capture any important social interactions between the children so that this work can also inform the sociological aspects of children's learning. Secondly, this work develops a timeline analysis approach to exploring how ideas evolve during a single session. This analysis is developed from the work of Givry and Tiberghien (2012) and aims to capture which children introduce new ideas and how these are developed and related to those already held. The aim is to capture exact moments of conceptual change in order to inform the mechanisms that underpin this.

## **Chapter 2 The Emergence of Constructivism**

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### **2.1 Introduction**

This chapter defines what constructivism is as it is commonly understood within the field of science education and discusses the historical perspectives of constructivism whilst highlighting the key theorists who promoted this view. Understanding the impact that such theorists have had on the development of the constructivist perspective in science education is vital here as this helps to elucidate the direction, and theoretical and philosophical underpinnings of this important research approach. In this chapter, both personal and social theories of constructivism are discussed and critically evaluated from a theoretical perspective and it is proposed that both of these aspects are important elements that require detailed understanding in order to inform how children construct their ideas in science (Fosnot & Perry, 2005; Driver, et al., 1994). The impact of these divergent perspectives is also summarised according to their influence on contemporary notions used in today's science classrooms particularly with reference to how these influence teaching, learning and curriculum design.

### **2.2 What is Constructivism?**

In science education, constructivism is a view of learning which, in its most basic and operationalized philosophical form, suggests that children behave similarly to scientists in that they gather information gained from experiences, observations and tuition and use this to formulate predictive hypotheses in order to understand the world in which they live (Driver, et al., 1994). These hypotheses may then be tested during subsequent experience and if confirmed actively shape a child's scientific knowledge and understanding. According to this approach, each child possesses a reality that they have constructed for themselves; a reality which is unique and offers insight into the experiences and interactions with the world that they have encountered (Piaget, 1929; von Glasersfeld 1995). However, it is notable here that

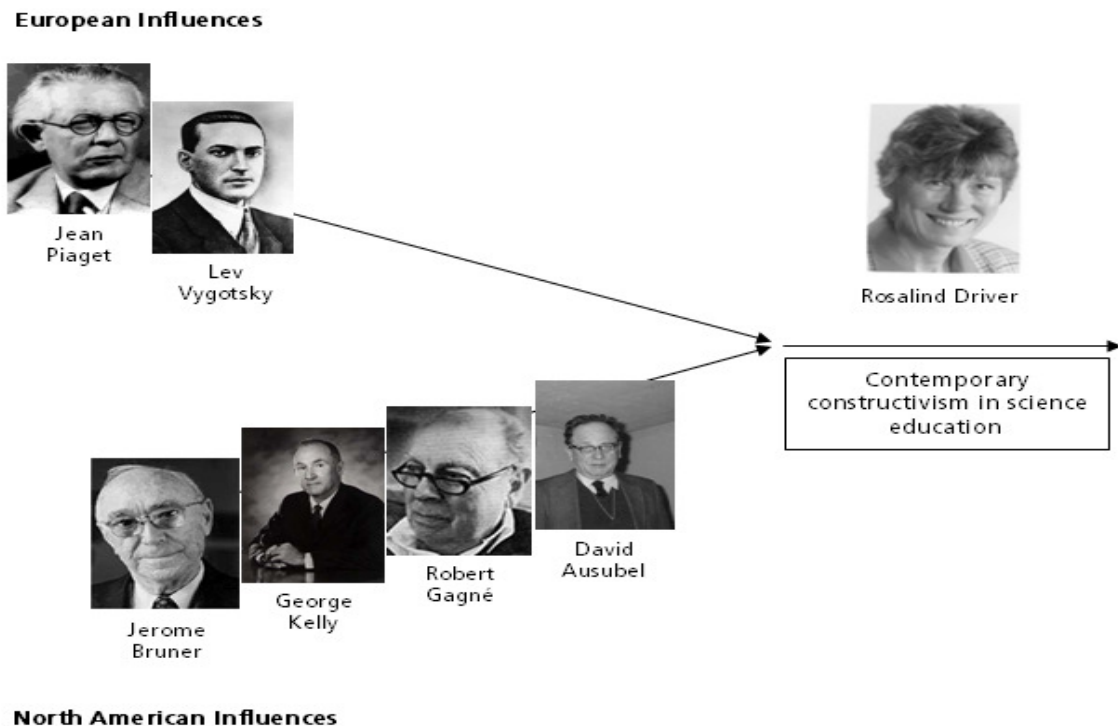
there are several issues related to these underpinning philosophical notions (Nussbaum, 1989; Prawat & Floden, 1994; Steffe and Gale, 1995; Bell, 2005) and the solipsism that this view is sometimes proposed to imply (Thompson, 1995). This has been subject to debate by contemporary authors such as Duit (1995) who claims that the social influence on a child's world view is such that individual and unique conceptions are rarely formed because of the shared experiences that they have. Central to, and underpinning all constructivist approaches is the thesis that, therefore, children are active participants in their knowledge construction and co-construction (Brook, Driver & Johnston, 1989) and as such meaningful learning tends to take place in many ways, not only through direct transmission. Applied to schooling, constructivism proposes that when children are undertaking formal science tuition in lessons they construct their own knowledge and concepts based on their experiences and reflection on those experiences within the learning environment (Driver & Easley, 1978). When new information is encountered it needs to be either reconciled with previous ideas or discarded as irrelevant. The exact nature of the outcome from formal science tuition is heavily reliant on the interpretations that children generate from the material presented and mediated in the classroom with other children and the teacher.

The particularly simple constructivist view of learning science mentioned also suggests that when children enter into formal classroom environments they already have some knowledge of scientific concepts and the world around them even if not understood or recognised in a formal scientific manner. It is important to note that the precise characteristics of this early scientific knowledge are often uncertain and debated in the literature with authors assigning different weight to the quality of children's early ideas arising. Thus far, such early ideas have been referenced to over time as quaint distortions (Piaget, 1929), errors (Bradley, 1996), misconceptions (Rowell, et al., 1990), preconceptions (Clement, et al., 1989) and alternative frameworks (Driver & Easley, 1978) reflecting the value attached. Whilst it could be argued that all of these terms are aiming to identify and categorise the same thing, e.g. an early conception of phenomena which is developed from an uninformed perspective, the terms used can carry a great deal of weight and can influence how they are perceived. By calling children's early or preliminary ideas misconceptions, for example, implies that these are incorrect. What is agreed in all of this is that

children may not formally recognise these ideas as scientific in the academic sense themselves. Clearly, children do develop in a world of dynamic experiences and through these experiences they learn from an early age to negotiate key scientific concepts such as motion, force, and causality, albeit in a simplified manner to the scientist working at the cutting edge of the field. Importantly, it is these early experiences that are fundamental to later learning and because of the individuality of early experiences it is anticipated that all children will come to their formal education with their own unique and often varying understandings. It is this view that is accepted almost unquestioningly by most science educators today. This chapter now turns to a discussion of the founders of constructivism in order to further explore the diversity of views and to introduce the contemporary view of constructivism in science education.

## **2.3 The Founders of Constructivism**

The constructivist movement arguably began with the work of Piaget (1928, 1929) in 1920s Europe followed by Vygotsky (1962, 1978). By the 1950s there was a second wave of constructivist views, this time originating from North America and in the educational context. The first was presented by Bruner (1966, 1971), followed by Kelly (1955, 1970), Gagné (1975, 1985) and Ausubel (1968, 1978). All of these different viewpoints underpinned the contemporary constructivist views of Driver (1973 onwards). This critique first explores the impact of each of these founders in order to facilitate a deeper understanding of the underlying similarities and differences between these distinct approaches to understanding how ideas develop. The early constructivist founders, captured in Figure 2 appears, at first glance at least, to demonstrate a linear development of ideas, however, there is a great deal of overlap and cross fertilisation between them and they often incorporated aspects of each other's work into their own (for example, Piaget's work was discussed and further developed within Ausubel's cognitive perspective on educational psychology). Thus there is a significant interplay between understandings and approaches to constructivism.



*Figure 2: Key authors of constructivist approaches to learning which underpin contemporary understanding of children's learning in science.*

The theoretical underpinnings of each of these approaches to constructivism ranges significantly in their depth and scope with each model placing a dissimilar focus on particular attributes of the individual's psychology and dissimilar emphasis on the driving forces behind the learning process (for example, Piaget proposed that it was maturation that drove forward the development of ideas whilst Vygotsky argued that the social environment and support from others provided a catalyst for change). It is proposed that rather than be considered discrete views of learning, the different approaches to constructivism can be better understood as a part of wider continuum that encompasses the domains of individuality as discussed in personal constructivism and sociocultural influences as discussed by social constructivism. Fundamentally, it may have been these theoretical lenses that the authors utilised that may have guided these distinct differences. For example, Piaget studied individual children using an approach that focused on their individual ability to undertake activities and discuss their ideas; this may have significantly influenced his focus on an individual's intellectual growth.

Global theories of constructivism are multifaceted, wide ranging and differ according to the weight attributed to personal and social factors (Piaget, 1974; Vygotsky, 1978; Tudge & Winterhoff, 1993; Phillips, 1995). It has been suggested that there are two key schools of thought, personal constructivism (Piaget, 1928, 1929; Kelly, 1955, 1970; Bruner, 1955, 1970; Gagné 1975, 1985; and Ausubel, 1968, 1978) and social constructivism (Vygotsky, 1962, 1978, and Bruner, 1986). Personal constructivism, sometimes referred to as cognitive constructivism (Ausubel, 1978), focuses on the internal mechanisms that operate within a child as they are acquiring new knowledge and skills, whilst social constructivism places an emphasis on the learning environment and the influence that peers, teachers and carers can have on development. Indeed for the purposes of this work it is proposed that acts of personal constructivism and acts of social constructivism are in fact both vital components of constructivism as a whole and both have a role in the formation of new knowledge and the development of ideas that already exist. Despite the debates what is clear is that it was these global approaches to understanding how and what children learn that led to a turning point in science education and the subsequent development of a more domain-specific approach (e.g. Driver & Easley, 1978; Driver & Erikson, 1983; Driver & Bell, 1986).

### **2.3.1 Piaget and Genetic Epistemology**

The creation and establishment of the constructivist school of thought is most widely accredited to Piaget, considered to be '*the great pioneer of the constructivist theory of knowing*' (von Glasersfeld, 1990). Piaget's work was influential across a range of topics but it was particularly resonant with science education because Piaget's experiments with children often centred on scientific concepts. In his seminal work "*The Child's Conception of the World*", for example, he interviewed children using his 'clinical method' which was a combination of interviews and practical tasks designed to probe different intellectual abilities in order to uncover their ideas for astronomy concepts, a line of enquiry that is still particularly active in the science education research field today (e.g. Osborne, et al., 1994; Sharp & Kuerbis, 2006). In addition to his topics of choice, Piaget had unprecedented access to research participants and through an open agreement with local schools in Geneva his research team

were welcome to attend any school after lunchtime and use any of the children as research participants (Bliss, 2010).

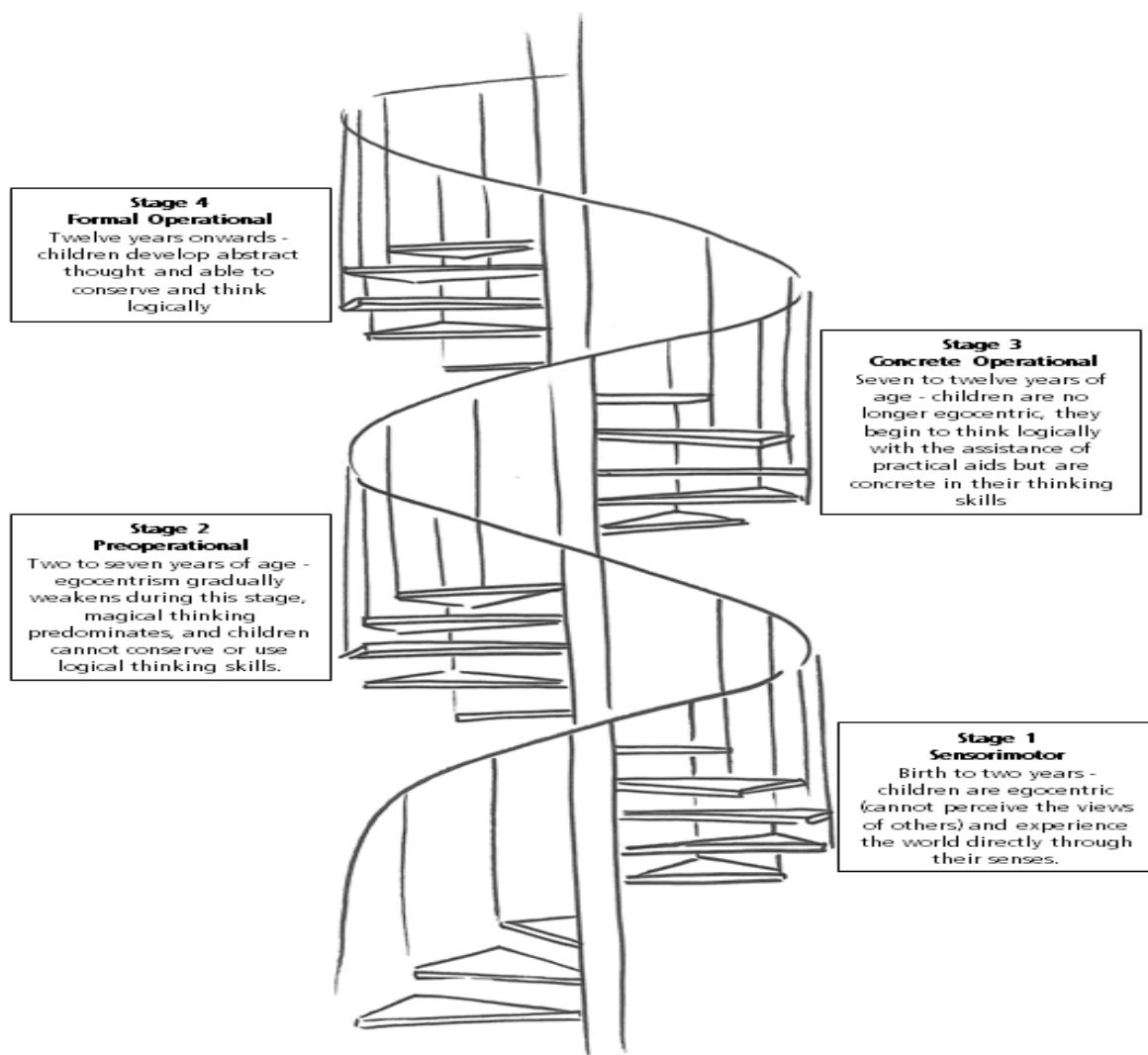
Piaget was a prolific writer and published extensively throughout his career. Drawing on his background in biology, Piaget's theory of genetic epistemology aimed to uncover the biological basis of intelligence (Piaget, 1980). In order to explore this, Piaget charted children's intellectual development across different ages. The research resulted in his development of a series of sequential developmental cognitive stages that he proposed explained the changes in children's abilities and ideas evident in his research findings (Piaget, 1929, 1960, 1964, 1974, 1980). Fundamentally, Piaget's theory was based on a theoretical approach that challenged the nature of truth and reality by suggesting that knowledge was an active and individual construction that depends on the experiences that a child encountered (von Glasersfeld, 1990) and the pivotal notion that "*The mind organises the world by organising itself*" (Piaget, 1937, p.311). This crucial proposal highlighted an important view of children's ontology, the nature of reality, and the epistemological exploration which is still used in science education research today. Piaget considered cognition to be a biological function rather than the result of impersonal reason, a view that was based on the ideas of the philosopher Immanuel Kant (1990). Kant suggested that knowledge is determined by an individual's way of perceiving and conceiving the world. Piagetian constructivism, as it became known, utilised an adaptive approach and suggested that all intellectual development could be understood as a child attempts to come to terms with, and work in synchronicity with, the world in which they live. It is important to note that within Piagetian theory 'intelligence' was an arising feature of the child's adaptation to their environment, thus intelligence was not defined as knowledge but rather the utility that arises from the ability to apply knowledge in order to operate within the world. Piaget proposed that children not only interacted with the world but were also transformed by such interaction, thus the two aspects share a mutually supporting relationship that facilitates change. Piaget agreed with Hegel's principle of *a priori* idealism (Hegel, 1971; deVries, 1988) but also added elements of empiricism to his theory. A central component of Piaget's approach was that all thought was fundamentally linked to action and as such, he suggested that:

*“...to know an object implies its incorporation in action schemes, and this is true on the most elementary sensorimotor level and all the way up to the highest logical-mathematical operations.” (Piaget, 1967, p. 17)*

As previously stated Piaget envisioned that knowledge developed through a series of progressive steps, often depicted metaphorically as a spiral staircase (see Figure 3), during which theses and antitheses of understanding interacted in order to generate new knowledge. Importantly, acquisition of progressive stages was accompanied by a more advanced level of understanding and qualitatively different cognitive skills. This approach maintained that knowledge consisted of self-regulating symbolic structures called schemes (Piaget, 1929). For Piaget, schemes were roughly defined as knowledge packets that were stored and interrelated in memory. Schemes contained information that guided behaviour and cognition as well as information regarding interaction and feedback gained from the environment. It was through these schemes that new information was interpreted (Cakir, 2008) and organised. In Piaget's theory (1929), schemes are developed through two key processes:

- assimilation – which occurred where new information fitted with the existing schemes held, thus new information was added into the knowledge that already existed;
- accommodation – which occurred when new information did not fit with the schemes that were already held, learning in this way occurred when the existing knowledge was changed or new schemes created.





*Figure 3: Piaget's 'spiral staircase' of the qualitatively distinct stages of intellectual development (staircase illustration Burnett, 2012).*

According to Piaget, as the schemes held by the child become more complex they begin to take the shape of structures, as the structures become more complex they become hierarchically organised within the cognitive system. Importantly, within this approach it was essential that some form of knowledge to which new information could be related already existed. Underpinning the learning process itself was the need for cognitive equilibrium or balance. According to Piaget (1928, 1929, 1960; 1980; Piaget & Inhelder, 1967) the child actively strives for stability, functionally described as the cognitive state of equilibration. Equilibration was a drive state that acted as a self-directing mechanism and promoted all learning. In support of his perspective Piaget presented extensive systematic evidence, for example, in

*'Children's understanding of causality'* (1928) the progress of children's knowledge of physics and their understanding of the characteristics of living things as they pass through his four stages of development was charted. These results were as follows:

- sensorimotor stage – birth to two years, children are egocentric (cannot perceive the views of others) and experience the world directly through their senses;
- preoperational stage – two to seven years of age, egocentrism gradually weakens during this stage, magical thinking predominates, children cannot conserve or use logical thinking skills;
- concrete operational stage – seven to twelve years of age, children are no longer egocentric, they begin to think logically with the assistance of practical aids but are concrete in their thinking skills;
- formal operational stage – twelve years onwards, children develop abstract thought and are able to conserve and think logically.

Piaget proposed that children's earliest understandings reflected a lack of boundaries between the self and the external world. Furthermore, Piaget (1928) stated that the following levels appeared within children's perceptions of causality:

- feelings of participation or magic, where the child is involved in or with the actions of nature;
- animism, in which consciousness is attributed to inanimate objects or events;
- anthropomorphism, in which consciousness and human attributes are attributed to inanimate objects or events;
- artificialism, in which the child considers objects or events as the product of human or god-like creation;
- teleology, in which creative activity is attributed to the objects or events themselves, phenomena having a predetermined purpose reflected in the outcome of their occurring;

- a kind of naturalism, in which every day occurring elements interact to produce an observed object or event;
- finalism, the idea of finality without the origins or consequences of an event or process being noticed;
- force, that things work in a way similar to human muscular action;
- physical or mechanical explanations which approximate to correct scientific solutions.

Thus it was proposed that very young children misconceived causality in objects by attributing characteristics such as objects operating under their own consciousness because they moved (Piaget, 1928). In the second stage of development causality was characterised by a confounding of moral and physical links and by the incorporation of both animism and artificialism. Animism was reflected in children's responses when they claimed that inanimate objects possessed some form of self-driven motivation that guided their behaviour (Piaget, 1928). Thus, it was common for children to perceive water contained within a river as having a will of its own by working toward a purpose (for example it flows to give people water to drink or make boats move forward). In the third stage of development understanding of physical objects and their subsequent movements were understood from a dynamic perspective (Piaget, 1928). By this age children came to realise that there were necessary features associated with movement and that objects were moved by forces. However, this understanding of forces was limited by the child's understanding and was thought to be similar to Aristotle's understanding of physics (Piaget, 1928). In the final stage of development (age 10 to 11); the child began to understand not only the mechanical explanation of movement but also was now able to appreciate rational principles (Piaget, 1928).

Piaget's approach was influential within the teaching community particularly with reference to curriculum design perhaps because it was the first theory that could be applied to such contexts. Notably Piaget's approach highlighted the ages at which children would be able to learn more complex ideas. According to Piaget (1930) teaching young children such knowledge too soon gives rise to the "quaintest

distortions” (p. 296), ideas that are not scientific but rather reflect the immaturity of the child’s mind. In adherence to this warning and as a way of using research to inform good practice in education the Schools Council Science 5-13 project, one of the first published science curricula, used Piaget’s framework to match teaching activities to expectations for children’s intellectual performance at given ages. Evidence of this can be drawn from the Match and Mismatch project (Harlen, et al., 1977a, 1977b). Shayer (1971) suggested that Piaget’s theory gave educators something to work with and as such the stages of intellectual development were used in order to assess the science projects of the Nuffield Foundation (Bliss, 1995). In support of this approach, research demonstrated that instructional design based on Piaget’s sequence of intellectual development had been successful for teaching aspects of physics to children (Bass & Montague, 1972). Supporting evidence for this view was also drawn from a range of studies including one by Sayre and Ball (1975) who presented evidence that children with lower attainment were classified in the lower stages of intellectual development. Sayre and Ball concluded that all teachers should be aware of the four stages of development in order to assess whether their children were ready for science tuition or not. In another study investigating secondary school children’s attainment of concepts in biology, chemistry and physics (Lawson & Renner, 1975), a multiple linear regression analysis of students’ scores on Piagetian tasks and scores on written science examinations revealed significant positive correlations. These results suggested that attainment of science concepts was easier for children who have reached an appropriate level of intellectual development, namely the formal operational stage. The study concluded that:

*“a substantial proportion of secondary school science subject matter may not be suitable in terms of the intellectual development of the learner” (p. 356).*

However, as well as guiding the science curriculum and children’s learning of scientific concepts the application of the ‘ages and stages’ theory to teaching practices was claimed to have been misused as a ‘get out clause’ in order to delay the teaching of more difficult concepts (Bliss, 1995). The notion of readiness that appeared within both Piaget’s work and the practice of some science educators was the subject of dispute (Bruner 1966). The results to recent research projects have

further illustrated that children can learn abstract concepts such as astronomy during primary school tuition even though they would be considered too young within the Piagetian theory framework (Sharp & Kuerbis, 2006). Further to this some of Piaget's central ideas have also been questioned including children's egocentrism (Donaldson, 1978) and the proposal that children think in a qualitatively different way (Keil, 1986; Carey, 1985). Indeed authors such as Carey (1985) propose that the evidence presented by Piaget could be re-interpreted to support a view that the differences between children's and adults understanding of science concepts may reflect the reorganisation of domain specific knowledge that occurs during the learning process and may therefore show evidence of expertise effects. Additionally, it is often claimed that while Piaget focused on individual development he did not account for the impact of the social world on the child and the ways in which this could facilitate their learning, however, discussion later will reveal that this may in some part be either a fallacy or a misinterpretation of Piaget's work. The development of Piaget's constructivist approach substantially impacted upon education in Europe but around the same time another key constructivist thinker was developing his own approach to constructivism which this time placed a greater emphasis on the social aspects of learning and proposed that internal processing was subservient to the external interaction.

### **2.3.2 Vygotsky's Socio-Cultural Approach**

Vygotsky was a Russian author who focused his research career on investigating children's learning as they passed through the formal education environment, and understanding the educational environment was fundamental to this view. Vygotsky (1962, 1978) suggested that the basis of cognition was social and cultural and that children's intellectual development could be supported by others through the process of social interaction. In particular the interaction between adults and children in the learning environment were central components of Vygotsky's approach. Accordingly, Vygotsky suggested that new functions first occurred within the social environment, these were then internalised and occurred again on a psychological level (Vygotsky, 1978). It was at this point that there was a departure between the theories of Piaget and Vygotsky. For Piaget acts are internalised first, but for Vygotsky they occur

socially before becoming a part of the child's cognitive repertoire. Vygotsky suggested that adults could support children's acquisition of more complex concepts through the Zone of Proximal Development (ZPD). The ZPD was a proposed space in which the adult could lower their ability to meet with that of the child and thus formulate a supporting environment that permitted children room to expand their intellectual abilities. According to Vygotsky (1978):

*"The zone of proximal development defines those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state."* (p.86)

It is important to note that like Piaget, Vygotsky suggested that there were restrictions on what children would be able to achieve within this space. Thus when teaching using the ZPD it was essential that educators only supported the development of concepts that were already beginning to form. Within Vygotsky's theory, language was proposed to hold a fundamental role as a mediator in children's development of thought (Cakir, 2008). It was suggested that through language children were introduced to a symbolic world and it was through these symbols and their use with others in the social environment that meanings were negotiated and come to be understood in a way that is acceptable within the culture (Driver, et al., 1994). One reason that Vygotsky held language central to his theory were his observations that children would use speech in order to direct their problem solving tasks. This led to the conclusion that:

*"...children solve practical tasks with the help of speech, as well as their eyes and hands."* (1978, p.26)

Vygotsky proposed that language and thought were fundamentally related and that it was through language that children were able to develop their thinking skills and develop concepts, thus language served an organisational role in the child's thinking. Concepts were defined as 'knowledge packages' that were stored within the child's mind. The form that concepts took depended on the way in which they had been learned. Vygotsky's framework discussed two distinct types of conceptions that children form: those that arise spontaneously or are based on the child's experiences

and thinking and those scientific concepts that are explicitly taught in school (Cakir, 2008; Moll, 1990). This view proposing that children had different types of concepts was further developed in the work of Solomon (1987). It was suggested that while taught concepts were highly systematic and organised, spontaneously constructed concepts were not. In fact Vygotsky suggested that everyday scientific knowledge consisted of a piecemeal collection of descriptive and explanatory fragments rather than a consistently organised 'theory'. Vygotsky proposed that the two types of concepts interacted and the more organised taught concepts provided a framework for understanding everyday knowledge. This in turn resulted in a transformation of the spontaneous or experiential concepts (Cakir, 2008). It was proposed that in order for this incorporation of everyday knowledge to occur "*thinking must move upward toward abstraction and generalisation*" (Cakir, 2008: p.195). In summary, it was through the incorporation of both everyday knowledge and science concepts taught in school that children attained an understanding of scientific knowledge that was highly organised. Tolmie et al (1993) suggested that within the Vygotskian framework, experience was not enough to support this acquisition; it must be mediated with words as this facilitated understanding in a wider context. One criticism often aimed at Vygotsky's approach was that he placed his understanding of intellectual development almost exclusively within the social domain. However, reference to Vygotsky's work (1978) demonstrated that he perceived a dual process of attainment based on the biological basis of elementary processes as well as on the socioculturally founded higher functions. Vygotsky (1983) asserted that:

*"A normal child's socialisation is usually fused with the processes of maturation. Both lines of development – natural and cultural – coincide and merge one into the other."* (p.22)

Thus, Vygotsky also perceived the importance of maturational development and the way in which such development supported the child's intellectual development. Indeed, like Piaget, Vygotsky proposed a stage-like theory for the development of concepts which proposed that only adults used true concepts (Van Der Veer & Valsinger, 1994). Whilst there have been many discussions regarding the differences between the theories of Piaget and Vygotsky, in some cases important discussions have highlighted the similarities between them (e.g. Vygotsky, 1984; Piaget, 1964).

The impact of Vygotsky's understanding of children's development of higher-level thinking has also been influential within science education most notably through its application to inform on classroom practice. From this approach if children are to learn then "*teacher intervention is essential*" (Driver, et al., 1994, p.7). The teacher's task, therefore, is to lead the children to the commonly held science understandings while providing appropriate experiences, including the use of appropriate language, for the children to acquire the appropriate scientific concepts (Driver, et al., 1994). In addition, the proposal from the sociocultural approach is that there needs to be scope in the classroom for discussion both with the teacher and with peers and this can help to facilitate the development of more organised science concepts. Vygotsky's work is particularly popular because of the social approach which is resonant with the everyday science classroom. Key authors such as Solomon (1983, 1985, 1987) support Vygotsky's approach and have provided evidence of social construction in the classroom. Having summarised the more important European constructivists, this discussion now turns to theories from North America.

### **2.3.3 Bruner's Process of Education / Curriculum Approach**

Bruner's approach to learning was been firmly embedded in a constructivist framework holding the central premise that learning was an active process. In his approach to education, Bruner (1966) firmly asserted that knowledge was not a product of teaching but a process that the learner participates in:

*"To instruct someone...is not a matter of getting him to commit results to mind. Rather, it is to teach him to participate in the process that makes possible the establishment of knowledge...Knowing is a process not a product."* (p. 72)

Bruner's view of learning implied that one of the central goals of children's education was to facilitate meaningful learning that assisted them in attaining the ability to go beyond the materials that are actually taught. Bruner, like many other constructivists, suggested that learners used their past and current knowledge in the construction of new ideas or concepts. Thus, his approach placed a great emphasis on the



knowledge that the child already possessed. In agreement with other constructivists Bruner stated that the learner actively selected and transformed the information that they received; they constructed hypotheses based on what they already knew and made decisions in light of the underlying cognitive structures that they held. In this context, Bruner defined cognitive structure as the schema or the mental models that the individual had stored in their memory. The cognitive structure was responsible for providing meaning and organisation to information and this enabled the individual to go beyond what is given in order to generalise learning to new situations. According to Bruner (1966), mental representations came in three forms and it was considered important that children were given the opportunity to progress any new material through these forms. The forms were:

- enactive – based in sensorimotor, action-based experience;
- iconic – image-based experience;
- symbolic – language-based.

Bruner proposed that these mental representations were progressive. At the most basic level of tuition it was thought important for children to engage with active opportunities to learn so that they were able to develop the enactive level of representations. Once these had been established the opportunity should be provided for children to develop iconic representations, and so on, until their ideas were located within symbolic representations.

In a pivotal text published in 1966, Bruner proposed that a theory of instruction should address four aspects in order to enable effective learning:

- the learner's predisposition towards learning;
- the way that a body of knowledge can be structured to enable it to be grasped by learners;
- the most effective sequences in which material can be presented;
- the nature and pacing of rewards or punishment.

In more recent work Bruner (1986, 1990, 1996) expanded these aspects to include social and cultural influences on learning and the influence that legal requirements can have on the provision of adequate education for children. In 1996, Bruner effectively turned his back on his cognitive roots and stated that:

*“...culture shapes the mind...it provides us with a toolkit by which we construct not only our worlds but our very conception of ourselves and our powers.”* (p. x)

As such, Bruner recognised that learning was not a solitary activity and that wider aspects of culture and the social environment influenced it, a point clearly illustrated when he stated:

*“...human mental activity is neither solo nor conducted unassisted even when it goes on ‘inside the head’...”* (ibid, p. xi)

Bruner’s contributions to learning can be summarised according to three principles resulting in his model of the spiral curriculum. Firstly, the experiences and contexts of instruction that facilitates the children’s readiness to learn needs to be carefully considered. Secondly, as previously stated in the four aspects that enable effective learning, instruction should be structured so that it is easy for the student to learn. If instruction is not appropriately structured this may form a barrier to understanding and prevent learning from taking place. Bruner proposed that one way in which this can be achieved is to organise the curriculum into a spiral. The spiral permits the learner to revisit concepts at different levels of abstraction over time, thus enabling children to progressively build on the cognitive structures that they have attained at an earlier time. Bruner stated:

*“A curriculum as it develops should revisit basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them...”* (1966, p. 13)

Finally, when designing instruction the materials used and the organisation of the material should facilitate the children’s extrapolation of the subject matter. Learners

should be encouraged to go beyond the information that is given. Bruner had undoubtedly greatly influenced modern theories of instruction and approaches to working in education; however, his influence within science education is much more difficult to locate. Most science education research refers to Bruner's proposals, specifically his notions of scaffolding, which is when adults facilitate children's learning by generating a supporting environment. However, there is little, if any, evidence of direct tests of his work within the science education field other than by association. Thus until this gap in research is filled it is difficult to discuss the exact impact that Bruner's approach to constructivism has had on contemporary understandings of how children learn science in the classroom even though his influences are evident in the curriculum that children in main-stream schools receive. Clearly, Bruner's work was drawn from the global context and his model of instruction was widely adopted. In addition, authors such as Driver (Driver, et al., 1994) frequently identified Bruner's contribution to science education.

Thus far the constructivists discussed in this work all locate their work in different fields of expertise. Bruner, for example, adopted an approach that was heavily biased towards the structure of education. In contrast to this approach, Kelly wrote extensively about constructivism from a therapeutic context.

#### **2.3.4 Kelly's Constructive Alternativism**

George Kelly was an American clinical psychologist who worked extensively to develop an understanding of how the unique view that each individual had of the world influenced his or her understanding of the phenomena that was experienced. Kelly's constructive alternativism approach supported the notion that each individual actively constructed his or her own knowledge of the world. Kelly (1955) suggested that all individuals should be perceived as 'lay' scientists who formulate hypotheses about expectations and test these in everyday interactions both within the social world and within everyday experiences. According to Kelly this form of human activity originated from a desire to predict and exert control within the world of experiences. Kelly proposed that information was formulated into personal constructs, forms of mental representation that contained information about concepts

and detailed the way that the world had been perceived. Personal constructs were interpretations of experiences and phenomena which according to Kelly were dynamic structures that were constantly in a state of revision. Constructs were revised in three key ways: firstly, they could be supported or made stronger, secondly they could be revised or altered in line with new information, or thirdly sometimes they were abandoned altogether when information was completely inconsistent with expectations. In his description of constructs Kelly (1955) stated:

*“Constructs are used for predications of things to come, and the world keeps rolling along and revealing these predictions to be either correct or misleading. This fact provides the basis for the revision of constructs and, eventually, of whole construction systems. If it were a static world that we lived in, our thinking about it might be static too. But new things keep happening and our predictions keep turning out in expected or unexpected ways. Each day’s experience calls for the consolidation of some aspects of our outlook, revision of some, and outright abandonment of others.” (p.14)*

Kelly’s approach placed a great emphasis on the role of the social environment in the formulation and the alteration of constructs, according to Kelly people also influenced the constructs that were held. Whilst in his original work Kelly’s approach focused on the development of personality, it has been suggested that the approach can easily be applied in the science education context in order to explain how children develop their ideas for science phenomena (Gilbert & Watts, 1983). Fundamentally the approach can be used to understand the individuality that is observed between the way in which children come to develop and understand scientific concepts and the ways in which children’s knowledge may evolve over time.

The application of Kelly’s approach formed the theoretical foundation of a thesis by Shapiro (1994) who adopted a personal construct approach to studying how children acquired their knowledge of the concept of light. Shapiro’s work is interesting for a number of reasons but the main strength of her approach is the manner in which she offered a systematic analysis of the individual learning profiles of six children in a 5th grade (American) classroom. In order to conduct the study Shapiro spent extensive

amounts of time in the classroom becoming acquainted with the children, the participants were selected according to their ability to interact with the researcher. The final sample included three boys and three girls, of which two children were experiencing learning difficulties, two were rated as average ability, and two were rated as high achievers. The study utilised many different approaches including videotaping sessions, working through activities with the children and helping the teacher in the classroom. The final data analysis was drawn from repertory grid conversations and case reports. The results demonstrated that children in the study would apply biases on their learning which were heavily dependent on their personalities and predispositions. The children's approaches to classroom activities were influenced by their personal approaches and their previous learning with the more outgoing children being happier to explore ideas whilst the more quiet children showed more reservation. Whilst interesting, it is difficult to see how the conclusions drawn from Shapiro's study can be applied to formal assessments of classroom learning particularly as this qualitative approach was perfectly feasible within the context of a research project but is beyond the scope of possibility for a teacher in a mainstream school environment. There is no doubt that all teachers take some account of the children's personalities and where possible their existing levels of knowledge when they are undertaking tuition. However, in a typical English school classroom of 30 children, teachers do not always have the time to make such individual assessments of students' learning on a day to day basis.

Despite the difficulties associated with the application of Kelly's work discussed here, the clear advantage of the constructive alternativism approach is the understanding that this facilitates for the diversity of knowledge found in the typical science classroom despite children having received exactly the same tuition. This view of constructivism does not however, provide any detailed analysis of the underlying cognitive processes that support learning. With the evolution of cognitive science it was suggested that when considering learning it was useful to explore an information processing view. From this view it is important to attend to the role that a child's memory, attention mechanism and behavioural performance can have on learning. One theory that takes all of these issues into account is evident in the work of Robert Gagné.

### 2.3.5 Gagné's Cumulative Learning Theory

Robert Gagné is best considered as a bridging theorist. Gagné took the best and most productive aspects of learning theory from the domains of cognitivism and behaviourism and embedded them in a constructivist framework of his own. Like other constructivist authors before him, Gagné asserted that learning was the result of the individual child's cognitive effort to construct their own knowledge of the world, and that learning resulted from the child's interaction with the external environment (Gagné, 1975). In agreement with behaviourist approaches, Gagné supported the notion that learning was characterised by changes in behaviour that were observable as outcomes of tuition:

*"...learning is process which enables organisms to modify their behaviour fairly rapidly in a more or less permanent way, so that the modification does not have to occur again and again in each new situation. An external observer can recognise that learning has occurred because of behavioural change and the persistence of this change."* (Gagné, 1975, p. 5)

This quote from Gagné demonstrates his understanding of how learning may be best summarised and identified. This view of learning as observable changes in behaviour still persists in education today. Influences from cognitivism can be observed in Gagné's explicit use of the standard information-processing model of learning and memory (see Figure 4). This particular approach was popular in psychology during the 1970s and many authors began to explore the way in which the limited processing capacity of the human brain could influence learning.

According to Gagné's information processing view there were a number of factors that could limit the processing capacity of the brain. These included attention mechanisms and memory mechanisms, most predominantly driven by short-term memory which acts as a buffer between the external world and the internal workings of the brain. A diagram of the typical interactions that are proposed to take place between different elements in the brain is provided (see Figure 4). According to this view, receptors in the brain pick up information from the environment; this

information is registered and passed to the short-term memory. Gagné attended to research investigating the short-term memory store (Millar, 1956). Millar's (1956) research demonstrated that all short-term memory processes were restricted to a 'magic number' of items that could be held at any one time, seven plus or minus two. Short-term memory is important for learning as this offers a temporary storage space in which information can be manipulated and related to previously held knowledge. Thus, if the short-term memory system is overloaded, items are lost or overlooked; the short term memory store is also subject to rapid decay so that items in this area that are not rehearsed will be lost and are not able to be recalled. The long-term memory contains the knowledge that is already possessed and is used to generate expectations, which is suggested to relieve the processing load. There is interplay between the two memory stores and both are responsible for generating responses to the incoming information. The responses produced, which are influenced by executive controls or higher order decision making, result in effectors and these have an impact on the external environment. Thus, information that is available to the learner acts as an input that is subsequently both stored and manipulated in order to produce responses. Fundamentally, Gagné's contribution to constructivism was the application of the information processing theory and the development of an instructional model.

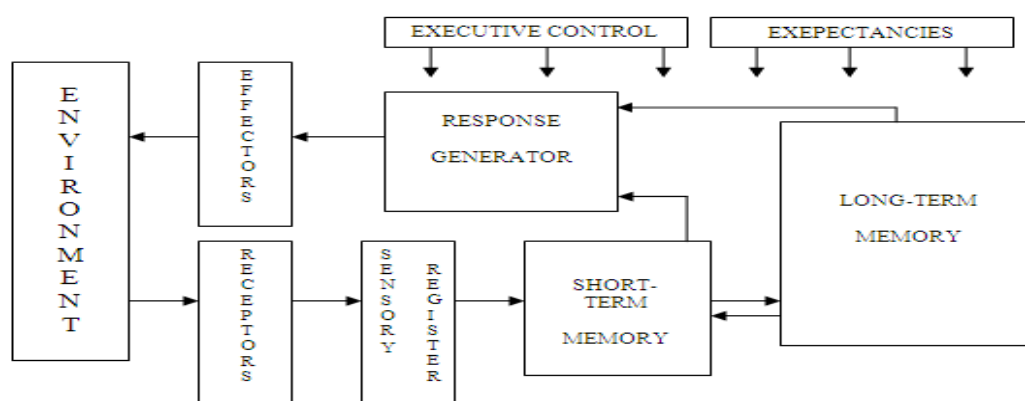


Figure 4: The basic information-processing model adapted from Gagné's *Essential of Learning for Instruction* (1975).

In particular Gagné emphasised the processes of thinking and remembering in his approach and focused attention on the methods through which instruction could be

designed in order to take account of the restrictions that were placed on the learning process by the cognitive architecture of the child. Gagné's approach to learning was comprehensive and elaborate and in order to explicate the multifarious processes of memory, attention and motivation Gagné suggested that there were discrete phases of learning (1975). Each phase of learning was associated with a particular behaviour on the part of the learner and a number of external events that can influence the opportunity for learning to take place (see Table 1).

<b>Learning Phase</b>	<b>Process</b>	<b>Influencing External Events</b>
Motivation	Expectancy	Communicating the goal Prior confirmation of expectancy through successful experience
Apprehending	Attention Selective Perception	Change in stimulation to activate attention Prior perceptual learning or Added differential cues for perception
Acquisition	Coding Storage Entry	Suggested schemes for coding
Retention	Storage	Not known
Recall	Retrieval	Suggested schemes for retrieval Cues for retrieval
Generalisation	Transfer	Variety of contexts for retrieval cueing
Performance	Responding	Instances of the performance (examples)
Feedback	Reinforcement	Informational feedback providing verification or comparison with a standard

*Table 1: Gagné's proposed phases of learning (1975), the processes associated with each phase and the external events that can be used by educators to facilitate learning.*



These phases of learning made it possible to segment each learning episode in order to facilitate the educators understanding of the processes that learners may be undertaking. One critical element of Gagné's approach was the 'essential incident of learning' (1975). This was hypothesised by Gagné to be the moment at which there was a change in the internal state of the learner from not learned to learned. Not only did Gagné clearly specify phases of learning he also proposed that there were five qualitatively different types of learned capabilities. These capabilities were verbal information, intellectual skills, cognitive strategies, attitudes, and motor skills. Each of these different learned capabilities was accompanied by strategies that could best assist in their development, for example when teaching cognitive strategies opportunities for developing new solutions need to be provided, when learning attitudes exposure to a suitable role model provided suitable learning opportunities. Gagné's model provided a more theoretical and empirically testable extension of Piaget, Vygotsky, Bruner and Kelly's theories. Gagné's work also laid the foundation that would appear in many different models of conceptual change developed during the 1970s and 1980s (for example, Osborne & Wittrock, 1983).

In 1968, Gagné also proposed a cumulative learning model that sought to explain the way that complex principles were developed based on combinations of simpler principles, thus he proposed that learning was progressive and heavily reliant upon what was already known. Gagné applied his cumulative learning model to the sequence that would be necessary in order for children to attain the conservation of liquid (a topic previously studied by Piaget and interpreted in accordance with his stages of cognitive development). In his analysis of this concept, Gagné proposed that children would not be able to demonstrate the ability to conserve the volume of liquid until they learned a number of underpinning foundation skills. For example, the subordinate learning of the rule that length, height, and width determine the volume of a liquid provided it is in a rectangular container and an understanding of the concept of solids and liquids (see Gagné, 1968 for a full analysis). As such, Gagné's analysis demonstrated that "*prior knowledge is the determinant for what further learning can occur*" (West & Fensham, 1974) and that a greater level of abstraction only becomes possible once certain foundational levels have been attained. This analysis was crucial to Gagné's appreciation of how learning occurs. The inability to

complete a task is not due to a deficit or developmental factor, it is simply a reflection of the current level of cumulative ability that the child had attained.

Gagné's approach has been influential within research literature investigating science education. In an analysis of the influence of prior learning on attainment of scientific knowledge, West and Fensham (1974) proposed that Gagné's analysis provided a logical structure through which educators could create an appropriate sequence of instruction. However, perhaps his most significant contribution has been through the work of Richard White. In White's book *'Learning Science'* (1988), Gagné's ideas were firmly embedded within his own constructivist approach to learning science. White refers to Gagné's proposal that prior knowledge provides the foundation for new skills and also draws on Gagné's distinction between different types of skills in his analysis of memory structures. Importantly, however, White also critiques Gagné for viewing learning as free from contextual processes. White proposes that although key theorists such as Gagné make a positive contribution to understanding of how learning occurs, they neglect to take into account the impact that the social and physical environment can have on children's learning.

### **2.3.6 Ausubel's Assimilation Theory**

David Ausubel, our final global theorist, developed his constructivist approach to learning within the field of educational psychology (Ausubel, 1968; Ausubel, et al., 1978). Ausubel's approach was another example of an early information processing view. However, in Ausubel's writing a distinction between meaningful learning and rote learning was drawn. Notably, for Ausubel meaningful learning was proposed to be associated with deeper understanding and the ability to apply knowledge across contexts whilst rote learning was proposed to be heavily memory reliant and context specific. In their analysis of Ausubel's approach to learning, West and Fensham (1974) proposed that rote and meaningful learning were opposing points on a continuum on which all learning takes place. The focus for Ausubel's approach was firmly embedded in meaningful learning and the methods that could be used by educators to promote this form.

Ausubel, like others, significantly diverged from Piaget's view of constructivism and suggested that the processes through which children acquire knowledge and develop new concepts were not stage dependent. Piaget's notion of learning through assimilation was, however, retained in order to explain how new knowledge interacted with what was already known. For Ausubel assimilation, or subsumption as he termed it, was a significantly different process. In the Piagetian approach, learning by assimilation was a domain general process and influenced the entirety of the individual's cognitive structure. In contrast, Ausubel proposed that learning in this way was only related to specifically relevant concepts (e.g. domain-specific rather than domain-general) and the process of learning in this way was perceived to be continuous process rather than occurring in discrete stages (Novak, 1977). Ausubel also stated that the primary determinant of learning was previous knowledge. In his most prolifically used quotation, Ausubel states that:

*"The most important single factor influencing learning is what the learner already knows. Ascertain this and teach accordingly."* (Ausubel, 1968: vi)

Ausubel's assimilation theory directly addressed the way in which prior knowledge influenced the processes through which subsequent learning occurred (West & Fensham, 1974). According to Ausubel's assimilation theory, six basic principles apply:

- subsumption;
- superordinate / subordinate learning;
- progressive differentiation;
- integrative reconciliation;
- obliterative subsumption;
- advanced organisers.

Subsumption was the process through which new information was organised or incorporated into existing knowledge structures. Thus existing knowledge acted as an anchor for the new learning. Ausubel proposed that this occurred in a hierarchical

or categorical manner through the other processes to subsumption and knowledge that acts as a 'subsumer':

*"A subsumer is any concept, principle or generalizing idea that the learner already knows that can provide association or anchorage for the various components of the new knowledge."* (West & Fensham, 1974, p. 63)

Hierarchical learning took place at a number of levels including superordinate, subordinate, and combinational. Superordinate learning took place when new learning enabled the individual to establish that existing concepts should be conceived of as more specific examples of an overarching concept. When learning took place in this way the definition of a new set of criteria attributes that encompassed the existing but now subordinate concepts existing within the individual cognitive structure were created (Ausubel, 1968). In contrast, subordinate learning was the process through which new information was linked to existing knowledge on a higher level of abstraction. Combinational learning differed slightly as this was a process by which new learning was derived from another concept or idea already existing in the cognitive structure but at the same categorical level (e.g. neither superordinate nor subordinate to the new information). This could occur by analogy.

Progressive differentiation was defined by Ausubel as the process through which existing knowledge is refined and developed into smaller ideas or concepts. According to Ausubel, when teaching took place it was most effective if the simple ideas were presented first and then gradually built up in complexity, by giving more detailed explanations later the learner was able to gradually differentiate between the key concepts. Progressive differentiation predominantly occurred because of the connections that were formed between fragments of information. Integrative reconciliation was also a form of differentiation. Here it was the links and new relationships that were made between concepts that were important (McGriff, 2001). The process of obliterative subsumption underpinned forgetting and it was promoted by the inability of learners to dissociate new information from existing concepts. Ausubel suggested that the amount a learner could recall depended on the meaningfulness that was associated with the acquisition of new knowledge. Thus if

learners were unable to dissociate new information from that which they already have learned they were less likely to recall new information later on.

The final principle that Ausubel proposed was the advanced organiser. Rather than discussing a learning process this principle addressed a method of using what was known about learning in order to support appropriate teaching practice. In order to ensure that children had some concept or subsumer to map or anchor new knowledge to Ausubel proposed that when engaged in the teaching process it was good practice to provide an 'advance organiser'. The advanced organiser contained a summary of the concepts that the child would learn. Once the advanced organiser was in place it was then possible to begin to relate concepts to each other in the cognitive schema of the learner. For Ausubel, the term schema was used to define packets of connected ideas or knowledge. Schemas could be related to objects, actions or experiences. One interesting proposal of Ausubel's that is infrequently discussed was that learners could experience an '*initial learning shock*', this was when the new information was in conflict with what was already known and the child found it difficult to accept. The initial learning shock had an impact on what was learned as well as the way in which it was subsequently recalled. Thus such learning shock could result in alternative conceptions, errors or misconceptions.

Ausubel's approach is significant for science education for a number of reasons. Firstly, his approach suggested that significantly younger children than those identified by Piaget were capable of learning higher level concepts provided that they already possessed the advance organisers or the subsuming foundational knowledge required. Indeed, in his book Ausubel critiqued Piaget's research and suggested that "*With respect to learning theory, Piaget had little or nothing to say*" (Ausubel, et al., 1978: p.230), Ausubel also stated that Piaget failed to specify in detail the process of assimilation and did not offer an explanation of exactly how the process of assimilation occurred. It was this lack of clarity that was fulfilled by Ausubel's assimilation theory. In addition, at the heart of Ausubel's theory is the notion of acquiring expertise that over time comes to reflect more intricate levels of complexity and more elaborated links with previous knowledge rather than reaching a predefined developmental level. This approach has particular resonance within the domain of science education where children are learning progressively more

complex knowledge and abstract concepts as they progress through their education. The application of Ausubel's assimilation theory directly to science education can be attributed to West and Fensham (1974) who suggested that assimilation theory provided a framework that explained how prior knowledge influenced the processes of further learning and how alternative conceptions form.

In their paper which reviewed the role of prior knowledge in learning science, West and Fensham (1974) also discussed the ways in which Ausubel's assimilation theory could be applied to science education in order to support educators in their delivery of this complex and highly structured curriculum. West and Fensham (1974) identified two generally agreed factors that influence what children will learn in their science education: what the learner already knows and their interest or motivation, which Bruner (1966) called the 'will to learn', for learning the subject matter. The authors proposed that these two factors were both necessary but insufficient for developing children's understanding of scientific concepts alone. The focus of West and Fensham's analysis is on the role that prior learning has on children's development and support the view that Ausubel's approach is a *"useful' theory of how prior knowledge influences learning of science"* (p.62). In their analysis of evidence that covers a variety of research domains including investigations into cognitive structure change, computer simulations, the role of irrelevant subsumers and evidence for advance organisers, West and Fensham concluded that although this evidence could be open to alternative interpretation it was strong enough to support the application of Ausubel's theory in science education. For example, a study by Ring and Novak (1971) which investigated the existing features of the cognitive structures in college chemistry students before and after college tuition revealed that the presence of subsumers before tuition positively supported the students' later learning. A second study by Shovelson (1972) presented evidence to support the notion that during tuition on a physics topic the learner's cognitive structure was significantly changed as learning occurred. This led West and Fensham (1974) to make a number of recommendations on the implications for teaching that were evident when viewing the learning of science from Ausubel's perspective. The most fundamental of these was that the prior knowledge that children possess has a dual role in the learning process, *"it sets basic limitations on what subsequent related learning can occur, and it influences how the learning can occur"* (p.79). This view

was upheld by White (1988) who accredited the strong role that prior learning can have on science learning to Ausubel. White suggested that Ausubel's approach demonstrated how prior learning could negatively influence children's attainment of scientific concepts as it could support them in the construction of different meanings to those intended by the teacher.

## **2.4 Discussion**

In this chapter, the historical roots of constructivism as developed by the European and North American schools of thought have been discussed (Piaget, 1928, 1929; Vygotsky, 1962, 1978; Bruner, 1966, 1971; Kelly, 1955, 1970; Gagné, 1975, 1985; Ausubel, 1968, 1978). In this discussion, it was revealed that for some the focus of their work was on key areas of scientific knowledge. For example, Piaget's work had focused on ideas related to astronomy, causality and floating and sinking objects (Piaget, 1928, 1929; Inhelder & Piaget, 1958). Such work was directly and easily generalizable to a science education context. However, such work was also heavily criticised by some for ignoring the social influences that are at play in a classroom environment. The importance of social interaction and relationships was central to the work of Vygotsky (1962, 1978). For Vygotsky, all knowledge and concept growth began with interaction in the social world, a view that was echoed in the work of Kelly (1955) who stated that people were learning about events in the same way as experiences. Importantly though, Vygotsky also supported the notion that knowledge and concepts were represented in the mind of the child in the form of mental representations. Furthermore, it was these mental representations that changed as knowledge was developed. This view of changing mental representations featured heavily within the North American theorists' work and for Bruner (1966), Gagné (1975) and Ausubel (1968), the formation of mental representations was important and links were made between these processes and the developing discipline of cognitive science. Importantly, however, Piaget's work was used as a foundation for later developments such as the theories of Ausubel (1968, 1978) who used the process of conceptual development as a foundation in order to propose his own view of conceptual growth.

In contrast, other theorists' work such as that presented by Kelly (1955), focused on the development of personal views of the world and as such may be harder to match to the science context. However, as demonstrated within this chapter, even though approaches such as Kelly's may not have directly linked to children's ideas in science, the underlying principles have still been applied at least in a research capacity (e.g. Shapiro, 1994). In general the influence of the founders of constructivism was wide reaching and had implications for many different subject areas. In order to sum up the discussion provided in this chapter the positions of the founders of constructivism are summarised for direct comparison (see Table 2). This summary explicitly aims to explore the importance of the founders in the development of constructivism as it is generally accepted in science education today and therefore the specific impact on science education has been included.

All of the early founders of constructivism had some form of impact on education and there is evidence that most of their ideas can be seen to have influenced science education and indeed approaches used in the science classroom. These views, whilst offering slightly different perspectives on the learning process, all generally agreed that learning depended on the previous experiences that children have had, how new experiences are related to what is already known and how both of these are influenced by the social environment. However, these views are not without criticism and important work has proposed that much of the appeal of constructivism is based on its intuitive nature (Airasian & Walsh, 1997). Furthermore, others have attacked the umbrella term of constructivism that has been adopted by educators without due consideration to the range and that actually there are many different types and forms (Phillips, 1995). Such criticisms aside, by the late 1970s another revolution was about to unfold. This time the focus was purely based on science teaching and learning. The founders of constructivism gave rise to the domain-specific perspective of Driver (Driver & Easley, 1978) which paved the way for alternative frameworks research that is still prominent in science education today. The next chapter discusses this in more detail and provides a broader critique of constructivism itself.



Author	Name and Definition of Approach	Key processes associated with knowledge construction	Impact on science education and science education research
<b>Piaget</b> (1929, 1958, 1960, 1964, 1967, 1975, 1980)	Genetic Epistemology – theory of intellectual development through cognitive stages.	Knowledge is held in schemas, as new information is learned this is added to what is already known through two key processes: <b>Assimilation</b> - occurs when new information fits with the existing schemes held, thus new information is added into the knowledge that already exists. <b>Accommodation</b> - occurs when new information does not fit with the schemes that are held, learning in this way occurs when the existing knowledge is changed or new schemes created.	Foundation for contemporary approaches to constructivism in science education (Driver et al, 1994). Influential in early curriculum studies. Basis for contemporary theories of conceptual change in science. Heavily critiqued because to its ages and stages approach to children's knowledge development.
<b>Vygotsky</b> (1962, 1968, 1987)	Sociocultural approach – highlights the importance of the social environment in children's development.	Interaction between adults and children in the learning environment are central components. Language is a fundamental mediator in children's thought. New functions first occur within the social environment, these are then internalised and occur again on a psychological level. Distinction between spontaneous concepts (fragmented) and scientific concepts (highly organised). Everyday scientific knowledge consists of a piecemeal collection of descriptive and explanatory fragments rather than a consistently organised 'theory', tuition in scientific 'school' concepts provides the organising structure which supports the reorganisation of spontaneous concepts into theory like structures. Conceptual development occurs when information become more highly abstracted and organised.	Applied in science education research by Hodson and Hodson (1998) in their sociocultural view of science teaching. Fundamental to Driver's (1994) domain-specific constructivist view of science education. Used by Roth (2000, 2008) in the development of his understanding of how children learn from each other in science.
<b>Kelly</b> (1955, 1963, 1970)	Constructive alternativism – used to suggest the unique view of the world that each individual has.	Analogy of man-the-scientist, hypotheses about the world are formed and tested, this is how change takes place. Construction of knowledge occurs when the perceptual field is narrowed. Constructs (can be	Applied in science education research by Gilbert ( 2005, Gilbert & Watts, 1983) through the formation of a

		subordinate / superordinate) – are interpretation of events, channels through which mental processes run. These are created in response to experiences and facilitate prediction of the world of phenomena and are revised during change. Proposes condition favourable to change – use of fresh evidence, experimentation, availability of validating data.	research group investigating the application of this theory to the educational context. Used as the theoretical background for Osborne & Wittrock's (1983) Generative Learning Model. Foundation for Shapiro's study of children's understanding of the concepts of light (1994). Critiqued for its individualised approach.
<b>Bruner</b> (1966, 1971, 1986, 1987)	Process of Education / curriculum theory – the view that appropriate sequencing, organisation and adaptation to suit learners current developmental level promotes learning.	Knowledge is a process not a product. <b>Spiral curriculum</b> - to enable children to progressively build more abstract knowledge as they reencounter previous ideas. What children already know support later learning. Learner actively selects and transforms the information that they receive. Hypotheses based on what they already know are constructed and guide decisions. Cognitive structure (schema or mental models) are stored in memory. Cognitive structure is responsible for providing meaning and organisation to information and this enables the individual to go beyond what is given in order to generalise learning to new situations.	Influential in the construction of the curriculum across subjects.
<b>Gagné</b> (1968, 1975, 1985)	Information-processing view – a bridging approach incorporating elements of behaviourism and cognitivism in a constructivist framework.	Focused on the way in which attention, motivation, memory structures can influence learning. Learning is the process that modifies behaviour. Discrete phases of learning each with its own proposed outcome. The <b>essential incident of learning</b> – the point at which the individual moves from a cognitive state of not knowing to a cognitive state in which learning has taken place. Five different types of learned capabilities each accompanied by their own strategy for effective	Applied in science education research by White (1988). Focus is predominantly on effective teaching methods and raises the distinction between learning skills and concepts.

		development - verbal information, intellectual skills, cognitive strategies, attitudes, and motor skills.	
<b>Ausubel</b> (1968, 1978)	Assimilation theory – uses an information-processing model (the analogy of mind as a computer) which takes account of the way in which memory skills influence learning. This approach is suggested to be a weak form of constructivism (Ernest, 1995).	Focus on the distinction between meaningful and rote learning and the processes associated with these two forms. Previous learning is crucial to meaningful learning. Knowledge is held as concepts in memory, as learning occurs new concepts are added and existing concepts are related to each other. <b>Advanced organisers</b> – to give the students something to anchor new information to. <b>Subsumption</b> – the process of assimilation which occurs the following levels, <b>Progressive differentiation, Integrative reconciliation, Superordinate learning</b> - established ideas become more specific, and <b>Subordinate learning</b> – new information is linked to overarching ideas. <b>Initial learning shock</b> – impacts on what it learned and how it is remembered.	Applied within Driver's work on constructivism in science education (1994). Provided the basis for some contemporary theories of conceptual change in science.

*Table 2: An overview of the early global constructivist theories and their application to science education.*

## Chapter 3 Contemporary Constructivism: A Domain-specific Perspective

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### 3.1 Introduction

This chapter provides an overview of the body of research that led to the development and proliferation of the contemporary view of constructivism that is prevalent in science education today. Firstly, Rosalind Driver's important work which laid the foundation for the conceptual change movement is presented and evaluated. This work was enormously influential and with its inception marked the beginning of a new research area which aimed to map the ideas that children had for different science topics. The most influential science education research programmes and their contribution to the research field are discussed. It is highlighted how such studies have been used in order to explore the way that children's ideas change both over time and in response to instruction. This mapping of learning led to a conceptual change movement which used the background of constructivism to explore the processes that are proposed to underpin such knowledge change. This resulted in a number of models being generated. Some of the more important of these models are reviewed in the subsequent sections in this chapter and it is against these models that the results from the work in this thesis will be compared. These models of conceptual change also provide methodological insight that supported the development of the methodological approach detailed in subsequent chapters. This chapter then provides a critique of contemporary constructivism and the conceptual change perspective.

### 3.2 Rosalind Driver: a Constructive Revolution

Rosalind Driver is still widely regarded as one of the most influential figures within domain-specific constructivism and science education research (see Figure 2, page 12). If Piaget is considered as "*the great pioneer of the constructivist way of knowing*" (Glaserfeld, 1982) then Rosalind Driver is perhaps best conceived as the '*founding mother*' of the contemporary constructivist perspective. In a career that spanned more than twenty years, Driver published an extensive body of work on

children's ideas in science and prompted the conceptual change movement which is still considered to be one of the most fruitful research programmes today (Taber, 2006). Importantly, Driver's work also spanned curriculum development (Driver & Oldham, 1986), attitudes towards science (Driver, et al., 1994), issues related to the development of scientific argument (Driver, et al., 2000) and processes in science learning (Brook, et al., 1989). Perhaps one of the key contributions of Driver's work was the introduction of the metaphor of 'student-as-scientist' (Driver & Erickson, 1983), which embodied the underpinning values of constructivism. However, this view of student-as-scientist was not without its criticism. Hodson (1998) has suggested, for example, that not all personally constructed knowledge is valid or indeed scientific. Importantly, the goal of science education in school is not for children to construct their own scientific knowledge but for them to co-construct knowledge that is representative of requirements at different levels in the curriculum. Criticisms aside, Driver's research publications and academic textbooks have been immensely influential in science teaching (for example Driver, et al., 1985; Driver, 1993). In her pivotal paper with co-author Easley in 1978, Driver reviewed a large body of research evidence as well as incorporated the results from her own doctoral thesis in order to critique the view that children held misconceptions regarding their scientific knowledge. Driver asserted that negative connotations associated with the word 'misconception' neglected the underlying learning processes involved and the power which children's intuitive science displayed. Driver sought to replace the language of misconceptions by proposing that children's ideas would be better perceived as reflecting alternative frameworks of understanding. Alternative frameworks influenced what children would learn when exposed to formal tuition in the science classroom.

In 1986 along with her colleague Beverly Bell, Driver arrived at the series of tenets which remain today. In more detail:

- learning outcomes depend not only on the learning environment but also on the knowledge of the learner;

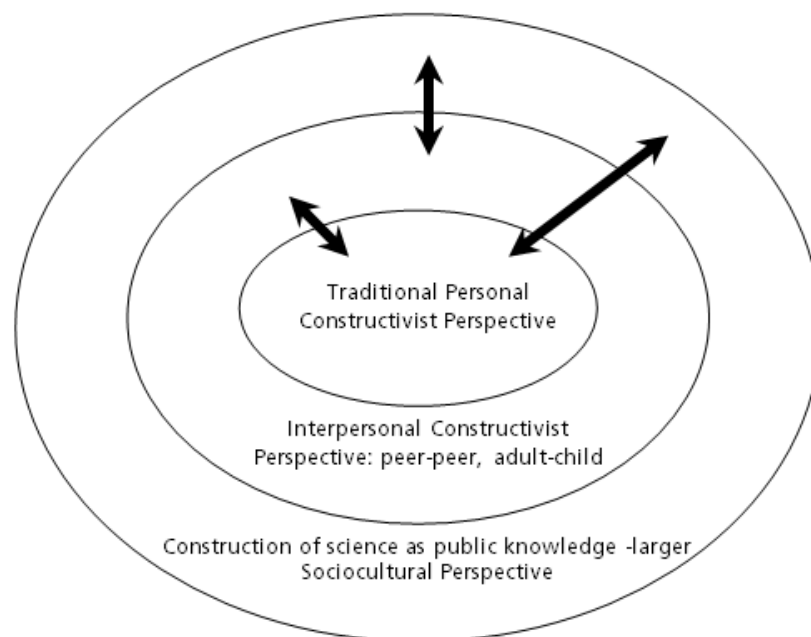
- learning involves the construction of meanings and meanings constructed by learners from what they see or hear may not be those intended (construction of a meaning is influenced to a large extent by our existing knowledge);
- the construction of meaning is a continuous and active process;
- meanings, once constructed, are evaluated and can be accepted or rejected;
- learners have the final responsibility for their learning;
- there are patterns in the types of meanings learners construct due to shared experiences with the physical world and through natural language.

One problem with these tenets is that they do not clearly explicate the underlying mechanisms that support the learning process, a criticism that can also be applied to global theories of constructivism and which will be revisited later. In a pivotal textbook exploring constructivist views of learning edited by Steffe and Gale (1995) Driver presented a chapter that somewhat clarified her thinking with regard to these underlying mechanisms.

*“The process by which knowledge is constructed by the learner is broadly surmised to involve a process of hypothesis testing, a process whereby schemes are brought into play (either tacitly or explicitly), their fit with new stimuli is assessed, and, as a result, the schemes may be modified.”* (Driver, 1995, p. 387)

However, this view that all children test hypotheses is subject to debate, not all learning is hypothesis driven and there is extensive evidence that children are capable of acquiring knowledge through other processes including rote learning (Ausubel, 1968). However in this 1995 text, Driver emphasised the importance of scientific knowledge being constructed both personally and socially as well as being validated within a wider reaching community, for example through teachers or schools. Thus, children’s ideas are not the solitary construction of an individual but rather reflect a process of, personal, interpersonal, and sociocultural interaction. Figure 6 summarises the way in which Driver (1995) conceptualised these three levels of constructivism interacting with each other. At the core of the model, the personal constructivist perspective operates within the individual. Personal

constructivism here is reliant upon the internal cognitive processes that operate in order to promote conceptual development (e.g. as proposed by Piaget, 1929). Personal constructivism is influenced by the interpersonal constructivism that embodies it. At this level, personal meanings are challenged, negotiated, and clarified through interaction with adults and peers in the social environment (e.g. as proposed by Vygotsky). It is at this level that issues related to curriculum and examination requirements impact on the knowledge and understanding that children develop. At the most external level the wider scientific community tests and validates the current state of scientific knowledge as generated by individuals and research groups. This validation influences the acceptability of constructed meanings at both the interpersonal level and the personal level (e.g. as proposed by philosophers of science, Vygotsky in 1978 and Solomon in 1987). Thus, all three views of constructivism interact in order to influence learning in a multifaceted manner.



*Figure 5: Embedded representation of the different levels of constructivism and the interaction between them in the development of scientific knowledge as proposed by Driver (1995).*

This interaction between conceptualisations on all three levels is the driving force behind the formal school learning process and the subsequent conceptual change

that takes place within the individual's cognitive schema. Driver's proposal that learning is conceptualised as a change in the schemas or cognitive structures within the individual and her interest in the way in which children's ideas in science develop and change over time promoted an extensive research programme investigating children's ideas across a wide domain of scientific knowledge.

### **3.3 The Influence of Research in Science Education**

Driver's work acknowledged the importance of studying children's ideas, at around the same time as her work was increasing in popularity the first of a number of influential projects aiming to map children's ideas in order to improve science teaching began. What is clear is that unlike almost all other subjects in the school curriculum science education was quick to begin to explore constructivism and what this meant for teaching, learning and curriculum design. A number of influential research projects were undertaken which aimed to uncover how children learn science in detail for the first time and map the development of ideas across and between different age groups in order to begin to unpack how ideas change. There were many projects but the most influential of these are detailed in this review. The first of these influential studies was the Learning in Science Project (LISP).

#### **3.3.1 The Learning in Science Project (LISP)**

The New Zealand Learning in Science Project (LISP) took place between 1979 and 1996. The project was funded by the New Zealand Department of Education and spanned five different research phases. The first phase of the project involved three stages:

- interviews with those involved in education;
- an exploration of the ideas that children bring to science;
- an action research project which aimed to develop and research new pedagogies in biology, physics, chemistry and general classroom activities.

This first stage of research was published by Osborne and Freyberg (1985) in their book '*Learning in Science: The Implications of Children's Science*'. In addition to this



influential publication, the project also resulted in the development of Osborne and Wittrock's Generative Learning Model (1983, 1985) which was both a view of the mind and of how learning takes place.

The second phase of research had a specific focus on primary education. There were two specific aims to this phase of the project: firstly, to investigate the problems experienced by primary aged children when learning science, and secondly to train primary teachers so that they could effectively support children's learning. The third phase focused on the teaching of concepts associated with energy as this spanned all three age groups within the New Zealand education system. The aim was for the research team to apply all that they had discovered with the younger children to a wider context. This phase of the project included the development of both a teaching unit for energy and an associated pedagogy. The fourth phase of the research project focused on teacher development and actively investigated ways that this could be supported. Bell (2005) reports that during this phase of the project four teacher development programmes and a total of 34 teachers of science took part in the training. The final phase of the project focused on assessment of learning.

Overall, LISP made a substantial contribution to constructivism at the time. The first stage of the project alone resulted in the production of 13 working papers and a substantial body of journal publications for different science areas including electricity (Cosgrove & Osborne, 1985) and floating and sinking (Biddulph & Osborne, 1984). At the same time as LISP was ending its second phase of research in 1984, science educators at the University of Leeds were beginning a broadly similar study, the Children's Learning in Science Project (CLIS), which aimed to explore constructivist views of learning science in England.

### **3.3.2 The Children's Learning in Science Project (CLIS)**

The Children's Learning in Science Project (CLIS) aimed to investigate children's ideas for topics covered during school science and to use these in order to inform teachers' practices in developing students' understanding of these topics. The project, undertaken by a team of influential science education researchers including Rosalind Driver and Phil Scott, focused predominantly on early secondary education,

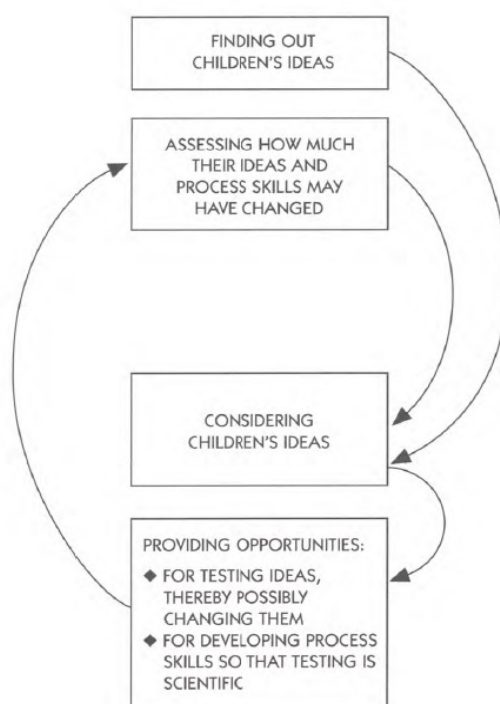
however, later publications considered children's ideas between 5 and 16 years (Leach, et al., 1995). The research team worked alongside teachers to develop teaching schemes for three key science areas: energy, particle theory and plant nutrition. The project begun in 1984, included an influential publication describing a constructivist view of teaching and learning (Scott, et al., 1987) adopting key tenets from Driver and Bell (1986). These included that:

- what is already in the learner's mind matters;
- individual's construct their own meaning;
- the construction of meaning is a continuous and active process;
- learning may involve conceptual change;
- the construction of meaning does not always lead to belief;
- learners have the final responsibility for their learning;
- some constructed meanings are shared.

According to the constructivist view of teaching outlined by Scott, et al. (1987), the project concluded that in order to support children's learning it was important for teachers to elicit children's ideas before they begin teaching science. It was proposed that such elicitation was important for two reasons: firstly, for children to develop ideas it was important for them to explicitly consider them and secondly, because if teachers are aware of the children's ideas they can plan teaching accordingly. Once children's ideas have been revealed; teaching that challenges or, in the case of appropriate initial ideas, further support can be provided. This provision of tailored tuition was suggested to support the restructuring or application of children's ideas. Once completed it was suggested that the final phase of the teaching loop could be entered. This phase was characterised by reviewing and consolidating any change in ideas.

### 3.3.3 The Science Processes and Concept Exploration Project (SPACE)

The Science Processes and Concept Exploration Project (SPACE) was funded by the Nuffield Foundation and ran from 1986 to 1990. The project was conducted from King's College London and Liverpool University under the direction of Paul Black and Wynne Harlen. The project had two underlying aims: firstly, to explore primary school aged children's ideas for a number of science areas and secondly, to explore whether it was possible to help children change their ideas through the provision of appropriate activities. The project was a collaboration between teachers and the researchers, where the teachers helped devise methods for eliciting children's ideas and establishing the techniques proposed to facilitate children's concept development. A number of reports and teacher training materials resulted from the project as well as a clear definition of an approach to facilitating learning in the classroom (see Figure 6 for an overview).



*Figure 6: An overview of the SPACE approach to teaching that was generated during the project.*

According to the SPACE approach, all tuition in science required the initial elicitation of children's ideas, followed by a consideration of what these were in order to plan appropriate activities for subsequent teaching which should aim to facilitate children's development of process skills as well as conceptual knowledge followed by an assessment of the changes made in order to plan further action. The SPACE approach to tuition bears striking resemblance to the constructivist teaching model first suggested by Scott, et al. (1987) during the CLIS project. Additional results from the SPACE project included the detailed mapping of the range of ideas that children had in the different concept areas including earth in space (Osborne, et al., 1994), electricity (Osborne, et al., 1991), forces (Russell, McGuigan & Hughes, 1998) and living processes (Osborne, Wadsworth & Black, 1992). However, one particularly helpful finding was the consistency across the range of ideas that children had across different schools and context. Through its massively influential range of curriculum supporting documents and reports the SPACE project had a substantial impact on primary science teaching. Whilst the three projects discussed above have all included some work investigating the usefulness of practical work in supporting children's learning a more recent research project, the ASE King's Science Investigations in Schools Project (AKSIS), placed its focus specifically on investigative work in science, the benefits that such work has for children and the problems that teachers encounter undertaking this form of work with children.

#### **3.3.4 The Association for Science Education King's Science Investigations in Schools Project (AKSIS)**

The Association for Science Education King's Science Investigations in Schools Project (AKSIS) funded by the Wellcome Trust began in 1997. The project which focused on investigative work in science, aimed to report on the current methods used in schools for teaching the nature of investigating work for children, identify successful practice and its benefits, identify areas where teachers experienced difficulty and review the National Curriculum, now well established for both positive and negative aspects. There were different phases within the research project and these included developing a framework, working with teachers to collect a range of data including teachers' diaries, videos of lessons and pupils' work, devising and

analysing a national questionnaire and working with teachers to improve practical work. It should be noted that this project was a specific departure from collecting children's ideas and incorporated the skills aspect of science rather than just knowledge of concepts. Importantly, implicitly embedded in this work was the sociocultural context of learning.

Through the research which included eliciting the views of 1000 teachers, 500 from Key Stage 2 and 500 from Key Stage 3, the project identified that six different types of practical science investigations were typically used within Key Stage 2 and 3 classrooms, 7 to 14 years of age. These were:

- fair testing;
- classifying and identifying;
- pattern-seeking;
- exploring;
- investigating models;
- making things or developing systems.

Interestingly the majority of practical science lessons were devoted to fair test investigations (50.4% at Key Stage 2; 82.6% at Key Stage 3). This led the researchers to conclude that an impoverished set of investigations were used at these two levels (Goldsworthy, et al., 1998a; Watson, et al., 1998b). Other important results revealed by the project included:

- no teachers used investigations to test out conflicting models;
- there was often confusion amongst teachers and children regarding the language used to describe and discuss investigations;
- less time was spent analysing and evaluating evidence than collecting it;
- there was a mismatch between teachers' aims for the investigations and the things that pupils consider that they learnt during the lessons.

The conclusions drawn from the AKSIS project were published by the ASE and subsequently recommendations for practice were made through a series of

publications (Watson, 1997; Watson, et al., 1998). Overall, however, what the project did reveal was that where practical activities were used in schools, these focused largely on the development of process skills such as how to use equipment and accessing appropriate data rather than focusing on the development of conceptual knowledge and using practical work to support changes in concepts. Thus suggesting that practical work was not being used effectively to support changes in children's ideas, which as a notion was fundamental to the domain-specific constructivist view of science developed by Rosalind Driver (Driver & Easley, 1978).

### **3.4. Children's Ideas about Electricity**

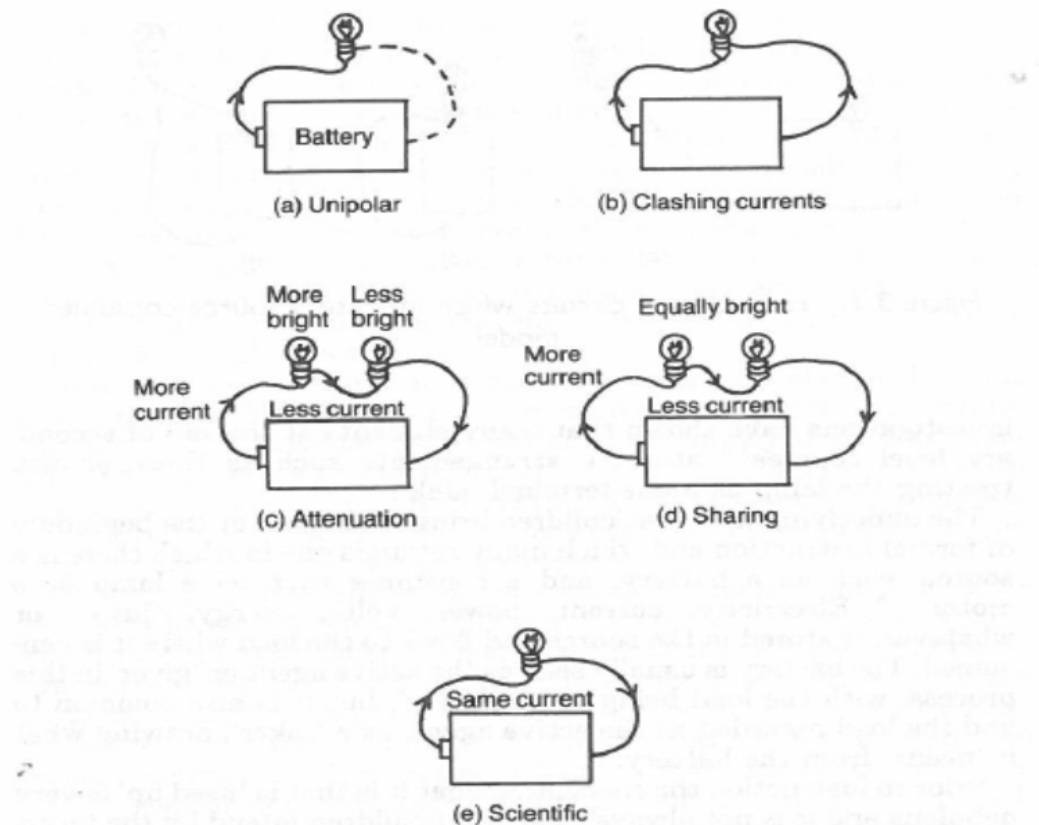
Like many other areas of science explored during the children's ideas research studies on electricity were frequently investigated in order to uncover what children knew about these topics and how the instruction of these concepts could be supported in the science classroom. Electricity is considered to be a difficult subject for both children and adults to understand. This is partly because children are expected to learn abstract concepts that are not directly observable and because most activities connected to learning electricity make it possible to observe the effects of electricity but not the actual processes themselves (Shipstone, 1985). It is because of this difficulty that children's ideas about electricity have been widely studied as part of most of the major research projects that have been undertaken to understand how children develop their ideas in this area and to improve teaching (Osborne, 1981, 1983; Solomon, 1985, Cosgrove & Osborne, 1985; Bell, 1991; Osborne et al, 1991; Shaffer & McDermott, 1992; McDermott & Shaffer, 1992; Fler, 1994; Cosgrove, 1995; Koumaras, Kariotoglou & Psillos, 1997; Kelly, et al., 1998; Psillos, 1998; Summerset, et al., 1998; Borges & Gilbert, 1999; Mulhall, et al., 2001, Clement & Steinberg, 2002; Sjøberg, 2002; Chiu & Lin, 2005; Finkelstein, 2005; Taber, de Trafford & Quail, 2006; Lee, 2007; Michelet, et al., 2007; Tsai, et al., 2007; Glauert, 2009). This review explores three important studies in more detail.

### 3.4.1 Shipstone's Electricity in Simple Circuits Study

Published in Driver et al.'s book '*Children's Learning in Science*', Shipstone (1985) discussed his research exploring children's ideas of electricity concepts. Shipstone identified five potential models that a child might employ when describing current flowing in electrical circuits. These models were as follows:

- the unipolar model – no current returns to the battery;
- the clashing currents model – current flows to the bulb from both terminals of the battery;
- the attenuation model – current flows around the circuit in only one direction and is used up in the bulb;
- the sharing model – where there is a series circuit the current is shared between the components;
- the scientific model – where there is an understanding that current travels in one direction through the circuit and is conserved.

Each model, which was developed using his own results and the findings from previous studies, represented a different and unique conceptualisation of the way the children thought electricity worked in a circuit. In order to show how these models worked Shipstone presented the following diagram. This shows the flow of the current that children suggested operated in each of the different models (Figure 7). What was interesting was that Shipstone's work revealed that the most prevalent models for electrical circuits observed in the younger children were the unipolar and the clashing model, both of which drop significantly as children get older (Figure 8). It was also revealed that the scientific model of an electrical circuit was rarely observed in the younger children but this became more prominent as the children got older (Figure 8). For example, by the age of 17 years just over 60% of the children interviewed used the scientific model to explain what they thought was happening in a circuit, whilst less than 10% of the 12 year old children used this model in their discussions.



*Figure 7: Shipstone's diagram representing the flow of current represented in the different models of electrical circuits discussed by the children in his study.*

Using data drawn from an 11 year-old-girl called Ann, Shipstone demonstrated how these models would be used in practice. One striking finding was that Ann would use different models depending on the clarity of the questions and the materials used during the probes. Shipstone proposed that the models used varied in popularity depending on the age and experience of his participants. In one example, Shipstone draws on research evidence from a study investigating the ideas for electricity that were present in secondary school and sixth form children at three schools and one sixth form college in the UK. All participating children had undertaken formal tuition in electricity that academic year. The results demonstrated evidence of all of the models with the exception of the unipolar model. Also drawing on data from a study in New Zealand, Shipstone proposed that the clashing currents model decreases with age and is less likely to be used. Interestingly Shipstone's study also addressed the use of analogies in electricity teaching, including the use of the water flow analogy. Importantly, Shipstone noted that the usefulness of analogies during



instruction relied on whether or not children understood the original concept fully, for example if they did not understand water flow then they would find it difficult to understand how this model could be used to represent electricity in a circuit, and whether or not children used the analogy to support an existing misconception. These findings demonstrated the importance of teachers using the ideas that children had a starting point and ensuring that teaching aids such as analogies would serve to support knowledge development rather than distort or impair it.

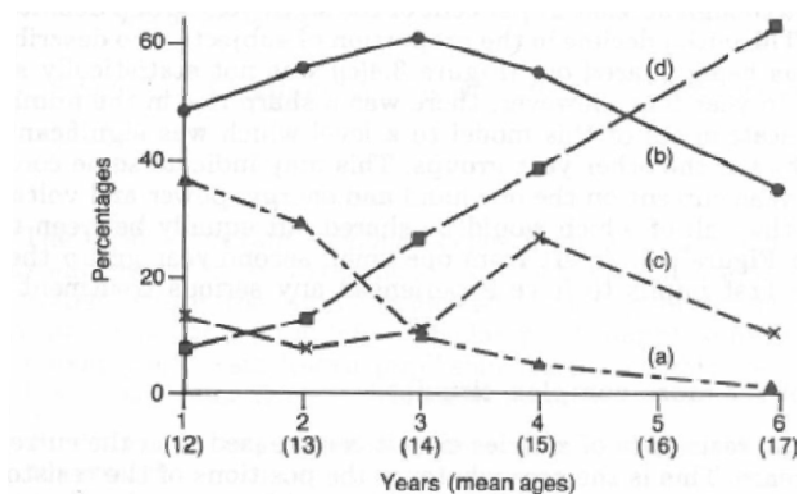


Figure 3.4: Variations in popularity of some conceptual models for current. (a) The clashing currents model, (b) all unidirectional non-conservation models, (c) the sharing model, (d) the scientific model.

Figure 8: Graph of Shipstone's results recreated from his publication in "Children's Ideas in Science".

Thus when Shipstone explored the commonly used analogy between electricity and water, he found that 54% of the pupils in his study were able to observe the similarity between these two forms of phenomena. 33% of the participants claimed that the analogy was helpful for developing their ideas, whilst only 27% applied the analogy to their work. Perhaps the most staggering finding was that only 6% of the participants used the analogy correctly. These findings have serious implications for teaching approaches that could be used with children, some of which are discussed further in Shipstone's work.

Overall this important work by Shipstone introduced a critical analysis of the potential models that a child could have and use when responding to prompts about their ideas for electricity. Evidence of the models identified for electrical circuits was found again during the SPACE project by Osborne et al. (1991).

### **3.4.2 The SPACE Electricity Study**

The Science Processes and Concept Exploration electricity study (Osborne, et al., 1991) aimed to investigate both the ideas that children had about electricity and how the development of these ideas could be supported through instruction. The SPACE electricity studies formed part of a wider research project which aimed to improve primary science teaching. The study took place in six London schools in the UK and involved infants (5-7 years), lower juniors (8-9 years) and upper juniors (10-11 years). The study employed a range of strategies for investigating the children's ideas. Clinical interviews were conducted with the youngest children and written responses were drawn from the older children.

The study revealed that nearly all of the children defined electricity in terms of a specific purpose, with the older children identifying it as a universal '*substance*' that had an 'independent identity'. The younger children who participated in the study often associated electricity with heat and fire whilst the older children demonstrated a tendency to discuss its properties. In addition the results reveal that children also often discussed the danger associated with electricity, e.g. that it can give you a shock (Osborne, et al., 1991). Another aspect of the study explored how children drew electrical circuits, this revealed that children's ideas fell into a number of categories, including:

- a single connection – where children drew in one wire to connect the battery to the bulb;
- battery connections, 1 device connection – where children drew in two connections at the battery but failed to acknowledge that the wires needed to connect to separate points on the bulb;

- 2 battery connections, 2 device connections – where children used the correct number of connections at both the battery and bulb but these were in the wrong place;
- 2 correct connections shown – where the children places the wires appropriately;
- no response – where the children failed to respond to the drawing tasks.

What was also interesting was that when analysing the different drawings some children failed to use the same model across all questions, showing inconsistency in the way that they used their ideas about a circuit. This finding was consistent with Shipstone's work (1985). Osborne, et al. (1991) also studied what children's ideas about conductivity were. In order to do so the children were asked to comment on six items (three conductors and three non-conductors) as to whether or not they thought they would conduct electricity. In addition the children were asked to plan how they would test for this. Overall the study showed that upper junior school children were able to effectively judge which materials would conduct electricity, the same pattern (although proposed to be less pronounced) was true of the lower junior school children whilst the infant school children demonstrated no clear ideas about conductors and non-conductors. The results also revealed that only the upper junior school children were able to propose an appropriate way that the materials could be tested for conductivity (e.g. using a complete circuit). It was found that the younger children either made no response or gave an incomplete response. Finally, the study also aimed to explore children's ideas about the effect that more batteries would have on a circuit. This revealed that responses regarding the bulbs in the circuit appearing brighter were relatively rare. However, whilst this study was particularly helpful for identifying the children's ideas about what electricity was Osborne, et al. proposed that the items used in this study failed to reveal children's models for electricity in any great depth. Thus although in the responses of one of the children there appeared to be evidence for a new 'pulse' model of electricity the data was not able to fully support this. Interestingly, the authors concluded that whilst the study had revealed age differences in the ideas held, context effects were also evident.

### **3.4.3 Borges and Gilbert's Study of Electricity Ideas in Secondary Students and Professionals**

This more recent study by Borges and Gilbert (1999) aimed to extend the work previously introduced and explore the mental models for electricity that were evident in a sample of 28 secondary age children (15 – 17 years old) and three groups of professionals (28 in total) who work with electricity on a daily basis. Borges and Gilbert proposed that previous studies which relied upon children constructing simple circuit and explaining what they thought was happening within them had only been able to reveal a partial understanding of the models that children had. This study aimed to tap into the participant's understanding of what actually changes the models that children hold and how these vary with age in more detail.

Borges and Gilbert used previous research to extend the range of possible models that a participant could reveal. Notably six models were identified as follows:

- unipolar model;
- two-component model;
- closed circuit model;
- current consumption model;
- constant current source model;
- Ohm's model.

These models begin with intuitive conceptions and build towards more scientific ideas data. The data used in the study was gathered using semi-structured interviews which consisted of a number of experimental situations. The aim was to use probes to uncover the individual's understanding of concepts and beliefs. All participants responded to the same questions. The results revealed a number of different conceptualisations for electricity. These included:

- electricity as flow;
- electricity as opposing currents;
- electricity as moving charges;

- electricity as a field phenomenon.

The researchers concluded that these results served to show how the questioning used by researchers can influence the results that are revealed. Borges and Gilbert also concluded that the results of their study revealed that participants can hold more than one model for electricity and that they can apply these at different times in order to respond to the challenges in hand (e.g. context affects). However, the secondary school children were less likely to discuss electricity as a field phenomenon, whilst they were most likely to include discussions of opposing current, perhaps because their tuition was only to this level. Interestingly the professionals who participated in the study rarely used the flow and opposing currents models, instead they tended to talk about electricity in terms of moving charges and field. However, the results of this study have yet to be replicated with younger children and it is proposed that it is unlikely that early primary age children will discuss their ideas of electricity according to the opposing currents model outlined by Borges and Gilbert (1999) largely because this age group will not have received tuition at this level yet.

Overall the results of the three studies reviewed here imply that children's ideas about electricity tend to become more scientific as children get older, that early ideas tend to be focused on describing the purposes and functions of electricity rather than the properties of the physical phenomena. This work is particularly helpful as a guide for the methodology employed in the current study and is helpful in terms of identifying teaching approaches that might be used in the classroom.

#### **3.4.4 Comments on Children's Ideas about Electricity**

The projects reviewed above all revealed a certain amount of consistency in the typical approaches that have been taken to measure children's ideas for electricity concepts. In all cases mentioned the children were given some form of drawing completion task, some questions designed to uncover their ideas about electricity and in some cases the opportunity to test these out. According to the research reviewed to date this approach has been particularly helpful for uncovering the different types of models that children used when considering what will happen in a circuit. Overall, the results of these studies have consistently revealed that children's

ideas about electricity develop from intuitive ideas to more scientific ideas over time. It is interesting to note that the development of ideas about electricity continues into adulthood and can be mediated by the profession that an adult has, for example if they use electricity in their daily work life then their approach to explaining how electricity works in a circuit will reflect this.

The evidence suggests that younger children tend to focus on the effects of electricity rather than what it actually is and that they often perceive that electricity in a circuit is used up by the bulb and does not return to the battery, whilst older children typically acknowledge that the current is conserved and that it continues to flow around the circuit. One particularly interesting finding was the lack of apparent consistency with which children apply their models of understanding. In conclusion, children's ideas for electricity is a well-researched topic, however, there are apparent difficulties associated with children's ideas, mostly because these can be difficult to measure and because they can show a lack of consistency depending on the context of the questions used during interview or elicitation.

### **3.5 Children's Ideas about Floating and Sinking**

Unlike electricity, children appear to be able to more easily access the principles of floating and sinking through observation. Indeed many, if not all, children have some first-hand experience of floating and sinking objects. However, although floating and sinking is more obviously visible than the flow of electricity, the formal scientific explanation requires a knowledge of forces which is less concrete. As with electricity there have been a number of significant studies investigating children's ideas for floating and sinking (Inhelder & Piaget, 1958; Rowell & Dawson, 1977; Biddulph & Osborne, 1984; Smith, et al., 1985; Halford, et al., 1986; Howe, et al., 1990; Kohn, 1993; Howe, 1998; Klein, 2000; Bloom, 2001; Havu-Nuutinen, 2005; Howe, et al., 2007; Howe, 2009) three of which are discussed here as these have been particularly informative for the current work. The first study of note is drawn from Inhelder and Piaget (1958).

### 3.5.1 Inhelder and Piaget's Law of Floating Bodies

Inhelder and Piaget's work (1958) investigated a wide range of topics, thus it is perhaps not surprising that they also studied children's ideas about floating and sinking and related these to Piaget's stages of cognitive development. Piaget's clinical method was employed, during which the children involved were asked to classify objects according to whether they thought they would float on water or not. The children were then encouraged to test these items and summarise the results.

Although the number of participating children is unclear, as is common with a great deal of Piaget's early work, the results presented took the following forms:

- contradictory or fragmentary explanations –in which the children incorporated multiple responses;
- weight – which sometimes progressed from weight in absolute terms to an early conception of density;
- type of material;
- characteristic “weight” of the type of material;
- density of the object – mass per volume;
- density – of the object in relation to the density of the liquid.

As with all of Piaget's previous work, the youngest children were more likely to introduce contradictory or fragmentary explanations, whilst the oldest children were more likely to introduce discussions of density that were related to both the object and the liquid. These results were interpreted by Piaget in terms of his stages of cognitive development. Thus it was proposed that as children get older they become more aware of the factors related to both the object and the liquid in which they are placed. Interestingly, however, the work by Inhelder and Piaget does not discuss the important role that the forces of upthrust and gravity can have in floating and sinking, nor do they discuss water displacement. In addition, as with all of Piaget's work, this study also appears to pay little regard to the influence of peers on the development of children's ideas.

### **3.5.2 Howe, et al.'s Peer Interaction in Floating and Sinking**

Howe, et al. (1990) aimed to build on Piaget's work on floating and sinking by examining what impact peer influences can have on the development of children's ideas. The study recruited a total of 121 children from across four age groups, 8-9 years, 9-10 years, 10-11 years and 11-12 years. All children were recruited from Glasgow in the UK. It is the pre-test to Howe, et al.'s study that is perhaps the most useful for the purposes of this review as it helps to reveal the developmental pattern of ideas related to floating and sinking that these different age groups of children held, however, the discussion will return to details of the post experimental changes towards the end of this section. All of the children participated in a semi-structured clinical interview. As with Inhelder and Piaget's study, the children were first questioned about objects, then provided with an opportunity to test these objects. The children were all interviewed individually. The interview results were coded according to the following content:

- failing to mention a physical property of the object;
- mentioning a physical property of marginal relevance to object density;
- mentioning a physical property partially relevant to object density but not showing understanding of density itself;
- mentioning a physical property that approximated object density or comparing weight of the object with water;
- comparing the objects' density with water.

Once all interviews were scored the children were grouped according to the models of understanding demonstrated. 58 of the children were grouped as appreciating properties partially relevant to density: 42 were grouped in transitional level between mentioning object properties that were partially relevant to density and mentioning properties of marginal significance: 18 children demonstrated more basic models than these; and 5 children demonstrated the more advanced model which was focused on density of the object compared to density of the water. These results as a whole appear to suggest that by late primary age the most common model found was one that incorporated properties of the object that are partially related to object



density. Following this pre-screen a total of 84 children were allocated to learning groups and encouraged to undertake a floating and sinking task during which peer discussions could arise, noted in the paper as study one. The children selected for the experimental element of the study were then given a post-test, which used the same materials but included some new questions. The results revealed evidence that children did alter their ideas about floating and sinking and there was strong evidence to suggest that the children could learn from discussion with peers who had differing but inadequate views of floating and sinking. These results are interesting because they were the first to capture the importance of peer discussions for developing ideas in this topic, and they show that often it is more beneficial if children are exposed to different opinions even if these are scientifically incorrect.

A second study was conducted with 72 of the children, once again allocated to groups for discussion and the completion of floating and sinking tasks, however, some new elements were added (for example, a real world instance about floating and sinking). The pre and post-test results were compared using analysis of variance, these statistics revealed that the children with differing but inadequate views of floating and sinking revealed the greatest change between the two measures. The evidence produced by these two studies supported the view that children's ideas during primary school tend to be focused on the properties of the object rather than those of the liquid and that children may not be attending to the object properties that will help decide whether it will float or sink (e.g. its density). Interestingly in this study, as with Inhelder and Piaget, the researchers did not focus on ideas of water displacement or forces even though an understanding of these elements would be expected if children held a scientific understanding of the phenomena of floating and sinking.

### **3.5.3 Havu-Nuutinen's Conceptual Change in Floating and Sinking**

Havu-Nuutinen (2005) focused on the development of ideas for floating and sinking that were observable in six-year-old children. The study also investigated the way that these ideas could be developed using constructivist based instruction and peer and teacher discussions.

A total of 10 six-year-old children took part in the study, the sample drawn from a pre-school setting in Finland. The full project took place over three stages, a pre-screen, instruction phase, and post-instruction interview. The aim of the pre-screen was to assess the ideas that the children already held. The children were asked what they thought the terms floating and sinking meant, what kind of objects float and sink and why, to draw objects floating and sinking, and make predictions about which objects would float or sink. The results of the interviews were audio recorded and later transcribed. The results revealed three outcomes evident in responses:

- non-relevant and non-scientific explanations – no mention of physical properties or responses relevant to floating and sinking;
- non-relational justifications based on weight, material or shape or air in the object and volume;
- water-related justifications.

It is interesting to note that, like other researchers discussed in this section, the categorisation scheme devised by Havu-Nuutinen does not include any discussion of forces or the role that these play in the phenomena of floating and sinking. This may be explained by the fact that these references were not used by children of this age. The children involved typically only used one property in their discussions of objects that float and sink prior to instruction. Only two children discussed the properties of the water in relation to the topic suggesting that at this age the children tend to attend to the properties of the object. Following the pre-screen the children were given instruction which was designed to help promote conceptual change in the children's ideas by using a collaborative and guided discovery learning approach. Fundamentally, the instruction focused on using social interaction during the teaching sessions to promote aspects of conceptual challenge which would support later learning of the concepts. During the instruction the children were also given the opportunity to undertake discovery learning which is defined as taking an active role in observing, predicting, exploring and describing floating and sinking (Ausubel & Robinson, 1969). Overall the results of the study demonstrated that following instruction the children had changed their ideas about floating and sinking with many of the children who had initially discussed the weight of the object as a reason for

floating and sinking, now being able to talk about the role that water had, for example, the children discussed the water 'holding up' objects. There was evidence overall that the children:

*"...used new concepts and their definitions were more accurate in the post-interview. The children were more able to describe in detail their justifications...unsuitable concepts were corrected and better ones were defined."* (p.275)

The study supported the notion that the application of instruction that was based on a constructivist approach could be successful in supporting children's development of ideas, even when these children were quite young. The study also emphasised the importance of collaborative talk with both peers and teachers for helping to develop ideas that are more scientific and facilitating conceptual change. However, criticism can be raised against this study as it utilised data from a small number of participants, thus the results may not be particularly representative of all children's ideas at this level and it may not be possible to find similar results within another sample of children this age. The categorisation system developed, however, was coherent and consistent with the previous research of Inhelder and Piaget (1958) and Howe, et al. (1990) even though it lacked detail of all aspects of science related to floating and sinking, for example, a discussion of forces and water displacement.

### **3.5.4 Comments on Children's Ideas about Floating and Sinking**

The projects reviewed above all demonstrate a certain amount of consistency regarding the way that children's ideas about floating and sinking have been explored. The typical approach taken in the literature was to ask children to define what they think floating and sinking is, what kind of items they think will float and why and then to provide an opportunity to test the items in order to check for accuracy. The results when taken as a whole appear to support the view that like electricity, children's ideas about floating and sinking become more scientific as children get older. This is noted in the responses of the children, where typically the younger children focus on surface characteristics of objects and neglect to appreciate any

role that the water may have in the floating and sinking process. As children get older they also begin to discuss ideas such as density. Indeed work has demonstrated that young children can be taught certain aspects of density even if they are not yet able to understand the concept fully. What is perhaps more interesting is the neglect of most researchers to include a discussion of forces within floating and sinking activities, this may in part be explained by the placement of floating and sinking activities in the curriculum which prevent it from being incorporated into such discussions. That aside, the work discussed in this section does appear to make a strong case for the use of peer and teacher talk and collaboration in supporting the learning process and this supports the idea that greater attention should be paid to the social context in which learning takes. In conclusion, the review of the literature on floating and sinking revealed that this topic has received less attention than the electricity topic in the literature, however, as with electricity, children's ideas become more scientific over time. The development of children's ideas about floating and sinking can be supported through classroom discussions and opportunities to explore materials and their behaviour in water.

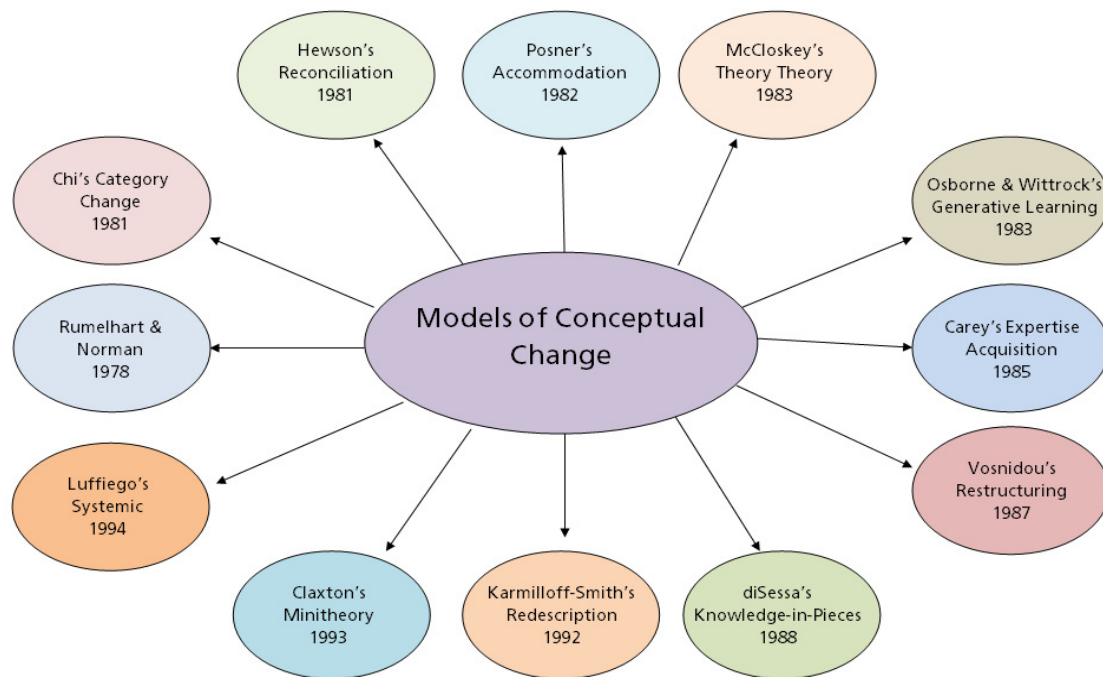
### **3.6 Learning as Change: the Multifaceted Face of Conceptual Change Research**

The research discussed so far illustrates the depth and scope of children's ideas in research. As discussed previously some studies have specifically aimed to explore how children's ideas change and the processes that underpin such changes. Research investigating the processes that underpin conceptual changes originating with alternative frameworks as established by Driver led to an extensive and wide reaching research effort which continues today. This effort resulted not only in a proliferation of outputs investigating children ideas in a wide range of science topics (Duit 2009 contains a recent list of publications) but also in the development of a number of models of conceptual change. These models were developed from a diverse range of theoretical positions. Founded in the work of philosophers of science, Toulmin (1953), Feyerabend (1962) and Kuhn (1962) and who all discussed the ways in which scientific knowledge has become radically restructured throughout the history of science. This analogy has been extended to the changes that occur within in children's concepts in order to explain the learning process (Driver, et al.,

1994; Carey, 1986). In her review of earlier work, Vosniadou (1987 and more recently 2007) proposed that children cannot merely rely on the ability to memorise scientific facts if they are to attain an understanding of advanced scientific ideas. Instead, Vosniadou proposed that advanced conceptual understanding only occurs when children learn how to restructure their intuitive or alternative frameworks. While characterised as conceptual change, what was less clear, however, was the actual mechanisms that underpinned it all.

Many authors have since produced models aiming to explain how restructuring occurs, ranging from, Osborne and Wittrock (1983) who incorporated an extensive body of research regarding memory and attention from the information processing perspective of cognitive psychology to Luffiego et al (1994) who developed a model founded on the principles of chaos theory suggesting that existing knowledge acts as powerful information attractors in order to facilitate later learning. Whilst a full analysis of all of the models of conceptual change is beyond the scope of this particular work, details of some of the most prominent models of change identified in Figure 9 are summarised in Table 3.

The models of conceptual change vary according the research that supports them and the theoretical backgrounds of those who have developed them. In many cases these different approaches appear to be capturing the same phenomena but offering different linguistic labels in order to explain subsequent findings. However, the linguistic labels that are attributed to conceptual change phenomena allude to qualitatively different levels of change. In Carey (1985), for example, the most extreme level of conceptual change is proposed to be strong conceptual change, whilst Vosniadou (1992) offers a perspective that accounts for radical conceptual change.



*Figure 9: 12 models of conceptual change identified from the research literature.*

Using the linguistic labels alone it could easily be suggested that a radical change in conceptual structure is very different to a strong change, with the term radical implying a more fundamental, far-reaching restructuring process. The term strong in contrast suggests a powerful change but not necessarily one that alters the very core of the concepts that are held. Whether or not the models differ purely according the linguistic competencies of the theorists remains to be explored in detail.

What is clear is that although all of the models discussed here have explanatory utility they cannot all be correct and remain to be tested formally. Nevertheless, four models have achieved prominence in the literature and these have relevance here (explored further later). Vosniadou, in particular, has reached prominence in the American literature and her model has been adopted by other theorists. The similarities and subtle differences are clearer when the models are considered in more detail. All four models are domain-specific views that resonate with the broader global theorists discussed in the previous chapter. To some extent all draw on the earlier models. These four important models will be used to tested through the data generated during this thesis:

- Vosniadou's weak and radical restructuring;
- diSessa's knowledge in pieces;
- Luffiego's chaos in cognition model;
- Karmiloff-Smith's re-representation theory.

These models were chosen because they help to illustrate the diversity of the field. Details of the other models of conceptual change identified in this work (shown in Figure 9, Table 3) were also included in important reviews such as West and Pines (1985), Limón and Mason (2002), diSessa (2006) and Vosniadou (2008) as well as in the original sources.

### **3.6.1 Vosniadou's Weak and Radical Restructuring**

Vosniadou has an extensive career history of investigating the development of children's ideas in science. In particular she has focused on the ways in which children develop their mental models in astronomy. In 1987, Vosniadou and Brewer suggested that the processes of accretion, tuning, and restructuring identified by Rumelhart and Norman (1978) characterise "the changes that occur as a product of learning" (p. 52) rather than the actual acquisition processes that children employ when they learn new information. In order to explore the changes in conceptual structure that occur as children acquire knowledge in astronomy Vosniadou and Brewer (1992) conducted a cross sectional study with sixty children in three age groups (average ages 6:9, 9:9, 11:0). The study investigated knowledge through a mental models framework. Mental models are dynamic structures that are proposed to be used when answering questions or solving problems, they can be constructed ad hoc or held in the memory but are proposed to be constrained by underlying conceptual knowledge. The children completed a 48-item questionnaire that was designed to illicit access to the concepts that children held in relation to astronomy through both verbal answers and drawings of the earth. The results demonstrated six different mental models of the earth, these begin with a flat earth model and over time this becomes a scientifically acceptable sphere model.

<b>Model of Conceptual Change</b>	<b>What is conceptual change?</b>	<b>What changes?</b>	<b>How does it occur?</b>	<b>Evidence for Model</b>	<b>What is prior knowledge?</b>
<b>Rumelhart &amp; Norman's Model of Conceptual Change (1978)</b>	The learning process that enables the child to bring new and old information into congruence.	The schema structures that the child has.	Three processes of change: Accretion – the addition of new information to what exists; Tuning – changes in the categories used for interpreting information, modification of schema; Restructuring – the development of new structures and the imposition of new organisation on existing structures.	Hypothetical model proposed on the basis in order to explain previous research findings.	Foundation for change.
<b>Chi's Model of Category Change (1981)</b>	A shift in the category to which concepts are assigned – change as replacement or creation of new categories.	Beliefs and mental models – from flawed to correct.	Gradual process of repairing incorrect conceptions, suggests to frequently occur on the categorical level: Tree switching – concepts move between categories, sometimes this may involve the development of a new categorical structure in which the conceptions can sit; Branch hopping – concepts move up (into superordinate, or basic level categories) or down (into subordinate or basic level categories) according to the new importance that is attributed to them.	Evidence drawn from: expert / novice problem solving in physics. The development of biological concepts in children.	Obstacle to new learning.



<b>Hewson's Approach to Conceptual Change (1981)</b>	An interaction between existing conceptions and new information that requires reconciliation.	Concepts.	Three ways in which new information can be incorporated: Memorised by rote; Replace existing concept with new one and reconcile new conceptions with remaining information through a process of conceptual exchange; Reconcile existing conceptions through the process of conceptual capture.	Case study evidence from a graduate tutor's understanding of special relativity.	The foundation for later learning.
<b>Posner, et al.'s Accommodation Approach (1982)</b>	A rational activity performed in order to comprehend and accept new ideas.	The concepts that the child holds.	Two processes of change: Assimilation – the addition of new information to what is already known; Accommodation – the replacement or reorganization of central concepts (Change instigated on the basis of, dissatisfaction with old concepts, intelligibility of new information, plausibility of new information and the fruitfulness offered by the new concepts).	Interviews with college students undertaking problem solving activities.	The conceptual ecology features of the child (consists and ideas rooted in epistemological beliefs) which influence interaction with new ideas and provide conditions of change in order to motivate restructuring.
<b>McCloskey's Naïve Theory (1983)</b>	A change in theory that resembles the development of scientific knowledge.	Concepts as coherent and theory like structures.	Analogy is draw between the development of scientific theory changes and learning in a domain-specific field. Model is light on descriptions of the actual processes.	Experiments with college students, focus on physics.	An alternative theory that requires change in order to comply with current knowledge in the area.

<b>Osborne &amp; Wittrock's Generative Learning Approach (1983)</b>	A change in meaning / understanding induced by the need to predict and control events.	The schema system that is held in long term memory.	Links between experience and previous knowledge are made in order to generate comprehension models. If these models are evaluated as useful they are subsumed into the schema structure.	Hypothetical model based previous evidence.	A driving force for motivation, attention, perception, and the generation of new models.
<b>Carey's Acquisition of Expertise Approach (1985)</b>	A shift in domains specific expertise acquired over time when mastering a topic.	Concepts contained within theory-like structures.	Two restructuring processes: Weak – adding new information to existing structures and increasing the connections between concepts; Strong – addition of new information, increase in connections and shift in core concepts of knowledge structures.	Experiments with college physics students. Cross-age study of biological concepts with children aged.	Foundation for change.
<b>Vosniadou's Weak / Radical Restructuring Approach (1987 onwards)</b>	A change in theory.	A change in the mental models that are applied when answering questions (proposed to reflect changes in the underlying theory).	Two processes of restructuring: Weak – addition of new relations within conceptual structures, organisation of knowledge into abstract relational schemata; Radical – a shift in the theory held.	Studies exploring children's acquisition of astronomy concepts, one study in physics and recent application to mathematics education.	Obstacle because it can give rise to synthetic models or misconceptions as well as vehicle for change.
<b>diSessa's</b>	The process that	A change in	Changes in the relations	College and	Foundation of

<b>Knowledge in Pieces Approach (1988 onwards)</b>	organises what is known into coherent theory structures.	the structuring and coordination of the information held.	between p-prims, the development of overarching structures which coordinate the p-prims (co-ordination classes and causal nets). There is a move from fragmentation to coherency.	undergraduate physics students. Recent application by Taber (2008) to chemistry.	disorganised knowledge.
<b>Karmiloff-Smith' Representational Re-description Model (1992)</b>	The re-description of knowledge from implicit (tacit) and context bound to explicit and context free, a change in coding format.	A change in the availability of knowledge across contexts.	Initial knowledge is tacit and unavailable for verbal report both within the individual and to others. The context bound procedural knowledge is represented through a four stage approach so that it is transformed to explicit knowledge that at the fourth level becomes available for verbal report.	Studies with very young children investigating object permanence and basic level physics concepts. Recent application by Phillips (2007) to the balance scale problem.	Tacit procedural knowledge that forms the foundation of later learning.
<b>Claxton's Minitheory model (1993)</b>	Change occurs through the development of new minitheories or through modification of existing structures.	Minitheories which partially cover specific areas of experience (often tacit in children).	Three processes: Accretion – adding new information to what is already known; Integration – changing the structure of what is known to incorporate new information; Creation – creating a new minitheory to cover the new experiences.	Theoretical model based on analyses of previous research.	A situation dependent way of thinking or acting.
<b>Luffiego's</b>	The self-	A change in	Two processes of	Sharp &	Foundation of

<b>Systemic Model of Conceptual Change (1994)</b>	facilitated process of evolution in cognitive structures.	the structure and relationships of concepts contained in schema.	restructuring: Weak – the addition of new information, changes in the relationships between concepts and modification of schema; Radical – change in attractor concepts, formation of attractor subschema.	Kuerbis' (2006) study of children's development of astronomy concepts. Bloom's (2001) study of the development of the concept of density.	conceptual change by acting as an attractor for incoming information.
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*Table 3: An overview of the most frequently cited models of conceptual change.*

The diversity of responses collected from the children led to the authors' assumption that children's mental models are constrained by presuppositions and that in order for conceptual change to occur the presuppositions need to be reinterpreted within different framework.

In their conclusion, Vosniadou and Brewer (1992) suggest that the change process is slow and gradual and may give rise to synthetic models. Synthetic models are proposed to reflect the child's attempt to integrate new information into the existing framework. Vosniadou (1994) suggested that such a view may also explain why misconceptions occur.

*"Children's misconceptions often reflect quite clearly these attempts to integrate conflicting pieces of evidence."* (Vosniadou & Brewer, 1987, p.55)

Using these important findings Vosniadou proposed that restructuring could occur during children's learning and that this restructuring can take place across two levels:

- weak restructuring;
- radical restructuring.

Both restructuring processes are defined through examples which draw on the studies of expert and novices problem solving. Weak restructuring was proposed to occur when more or different relations between concepts were represented and through the organisation of knowledge into abstract relational schemata. In both of these instances, previous research by Chi, et al. (1981) had illustrated that experts and novices differ in this way, with experts demonstrating higher levels of organisation in their conceptual structure. In contrast, radical restructuring was proposed to occur when there is a shift in theory. Independent evidence for this view can also be drawn from studies which illustrate that experts differ from novices in terms of the theories that they hold, these theories differing in terms of structure, phenomena explained and individual concepts (diSessa, 1988; McCloskey, 1983). In order to fully explain the distinction between the two types of changes Vosniadou and Brewer (1987) stated:

*“The development of knowledge in the child can be seen in similar terms, as the process of enriching and elaborating existing “theories” that can give rise to theory change, in other words weak restructuring. Occasionally, when the child is faced with major anomalies that existing conceptual structures cannot account for, a new paradigm is required, giving rise to radical restructurings.”*  
(p. 54-55)

The authors do urge caution when using the analogy of paradigm shifting to describe the notion of conceptual change and suggested that it is important for researchers and science teachers to remember that for children the aim is to integrate current scientific views with their own experiences rather than to independently arrive at new ways of ‘seeing’ as science progresses.

In order to clarify their definition of radical restructuring, Vosniadou and Brewer stated that it can be considered to have taken place when the new schema differs from an older schema:

- in terms of individual concepts;
- in terms of structure;
- in terms of the domain of the phenomena being explained.

All three of these conditions are identical to those suggested by Carey (1986) who defined the process as strong restructuring. Significantly, applying Vosniadou and Brewer’s model of conceptual change to pilot findings (see later) it is possible to illustrate, support and provide empirical evidence of their position in floating and sinking (Figure 10).

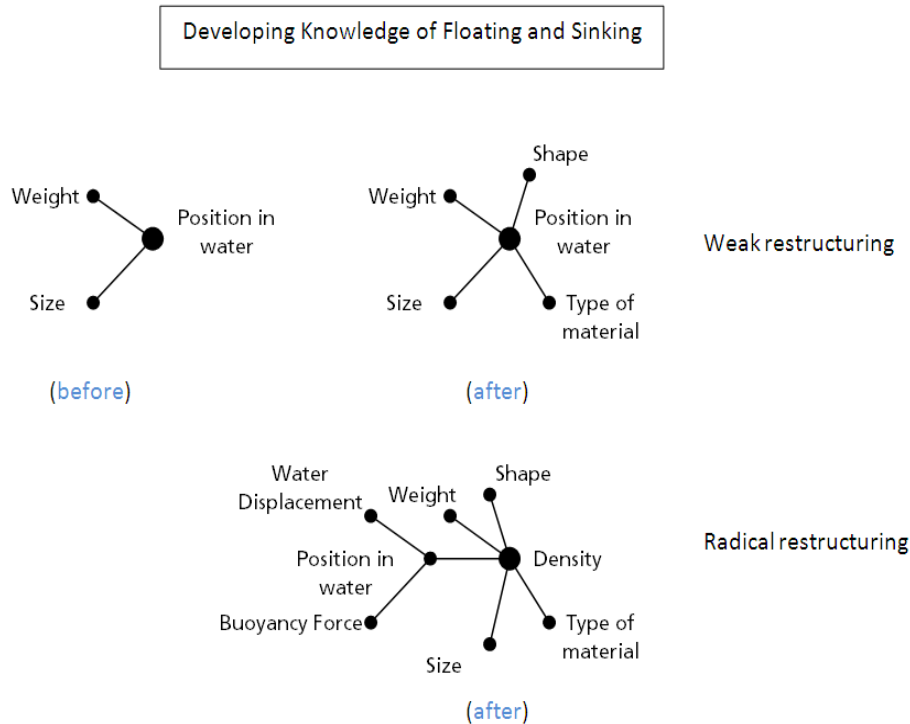


Figure 10: A potential illustration of weak and radical knowledge restructuring (Vosniadou & Brewer, 1987) from pilot findings in children's ideas about floating and sinking.

### 3.6.2 diSessa's Knowledge-in-Pieces Approach

diSessa's (1988, 1993) approach to scientific knowledge acquisition and concept learning also takes the view that the transition to scientific understanding involves a major structural change in knowledge rather than just a shift in content. diSessa proposed that intuitive conceptions of science can interfere with the learning of actual scientific information and as such learning science is difficult. One important aspect of diSessa's work is the refutation of the notion of learners holding naïve theories in favour of fragmentation. Naïve theories of science learning favoured by McCloskey (1983) stated:

*"...people develop on the basis of their everyday experience remarkably well-articulated naïve theories of motion. Further, we argue that the assumptions of the naïve theories are quite consistent across individuals. In fact, the*

*theories developed by different individuals are best described as different forms of the same theory". (p. 299)*

In contrast, diSessa (1988) supported the view that intuitive science is:

*"...nothing much like a theory in the way one uses that word to describe theories in the history of science or professional practice. Instead, intuitive physics (sic) is a fragmented collection of ideas, loosely connected and reinforcing, having none of the commitments of systematicity that one attributes to theories". (p.50)*

This led to diSessa's proposal that children and novices have conceptual structures that consist of knowledge-in-pieces. When adopting this view it was proposed that intuitive science knowledge existed as a large number of fragments of information or even a small number of integrated structures. These fragments were called phenomenological primitives or p-prims and could be understood as abstractions from common experiences. According to diSessa, p-prims are small knowledge structures involving only a few small parts. In some cases these parts entail behaviour or are behavioural in nature. Importantly, p-prims provided the learner with a rich vocabulary through which people remember or interpret experience. P-prims are developed from an early age which leads to diSessa's suggestion that although children do not enter into science tuition with theories they do have a select few example explanations that are utilised where necessary. By rejecting McCloskey's naïve theory view, diSessa proposed that there was no coherence to what children knew prior to formal science instruction. However, because p-prims were developed through experience there was an importance to having awareness of these and this was extended to the view that also suggested that experience (as felt internally) was important to tuition. diSessa (1988) stated that:

*"We cannot expect to have students learn things that are radically distant from their current state of understanding... Nor will they learn things that have a radically different character..." (p.61)*



The initial evidence for the existence for p-prims was drawn from a series of interviews with twenty physics students over a three year period. All the students were selected for their achievements in high school physics. Interviews took place for an hour each week during the student's first-term on their physics courses. The students were asked to apply 'think aloud' protocols during problem solving tasks. 'Think aloud' is a technique designed to enable researchers to gain insight into the students' thinking. The student is prompted to articulate all of their internal thought processes during the task so that underlying conceptual structure can be uncovered. The resulting evidence supported the claim that novice physics students do not appear to hold consistent initial theories. Instead, and consistent with diSessa's predictions, students at this stage of tuition applied different 'packets' of knowledge depending on the characteristics of the problems that they are attempting to solve.

This approach to conceptual change suggested that in order for change to occur the p-prims must become more systematically organised as well as covering greater aspects or different domains of experience. In order to explain this re-organisation diSessa (1998) proposed two additional types of conceptual structure: coordination classes and causal nets, both of which may be involved in the process of conceptual change. Thus, within diSessa's approach to conceptual change there are three hierarchical levels of abstraction (see Figure 11 for an illustration of the application of diSessa's model to pilot study results which provide empirical evidence of children's ideas for floating and sinking. For diSessa it is the organisation, relationships and explanatory scope of abstractions that change when children learn science.

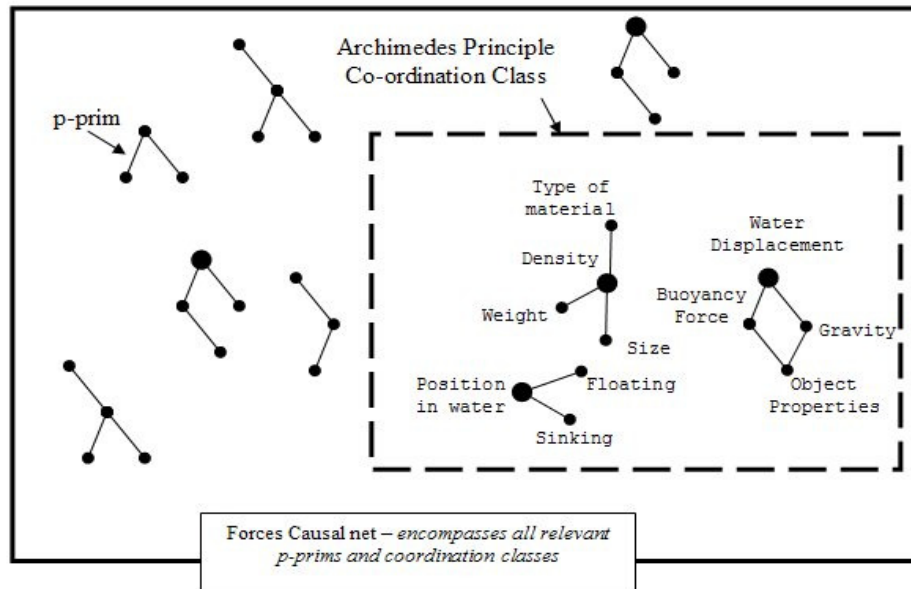


Figure 11: A potential illustration of knowledge restructuring according to the development of p-prims, coordination classes and causal nets (diSessa, 1988) from pilot findings in children's ideas about floating and sinking.

As previously mentioned, the first level of abstraction is p-prims which are small knowledge structures that contain a limited capacity to explain experiences at the most basic level. Coordination classes are defined as encompassing sets of p-prims, the coordination class contains information regarding the relations between the p-prims and strategies for coordinating these in order to solve problems. The next level of abstraction, causal nets, are proposed to bear more resemblance to scientific ideas and are the overarching structuring in which coordination classes and their constituent p-prims are contained. diSessa proposed that *"the separate changes in readout strategies and in the causal net constitute parameters of conceptual change"* (p. 1175). Thus it was proposed that conceptual change is characterised by changes in the p-prims, the development of or changes in the depth and scope of the relations between p-prims as contained in the coordination classes, as well as the development of or changes in the overarching theory structures, the causal nets. diSessa's understanding of conceptual change, therefore, is coherent with other perspectives of conceptual change. In agreement with other authors on conceptual change diSessa proposed that due the unique experiences that children bring with them to science tuition, learning scientific concepts is difficult and takes time.

diSessa's model is complex and valuable, offering an important insight into the possible development of new ideas and the way that these may become organised through experience, this resonates somewhat with the ideas of global constructivists such as Vygotsky (1978). However, diSessa's approach is less common than Vosniadou's perhaps because of the complexity of the language used in the description of knowledge changes, or perhaps because diSessa's work focused on older learners and some feel it is less applicable to children.

### **3.6.3 Luffiego's Chaos in Cognition**

In 1994, Luffiego, et al. proposed an intriguing model of conceptual change which builds on the premises of the General Systems Theory (Bertalanffy, 1968) and holds the central premise that conceptual construction is systemic and chaotic in nature. This systemic and chaotic model suggested that the brain and its learning capabilities could be best understood when viewed in analogy to other self – regulating systems, including for example, the weather.

According to this model, the cognitive system of the learner is responsible for the selection, processing and storage of information. The nature of the information stored is specific to the individual and exhibits unique and variable characteristics that reflect the individuality of experience. The conceptual schema or knowledge structures that children hold are not only a simple record of information but tools for studying reality and as such have their own dynamics that are independent of input from the external world. The systems are open and receive information from the external world of phenomena. In order to enable the child to understand this information the conceptual system produces answers that permit the prediction of events and problem solving abilities. Conceptual understanding of phenomena evolves iteratively through different states. Each state is a function of the previous state and the variables that influence it. Therefore it can be assumed that the conceptual system is influenced by numerous variables including motivation, information received and existing conceptual structures. In order for learning to take place it is proposed that the relationship between the phenomena in the external world and the individuals underlying conceptual understanding never have balance, balance would make information input impossible. In its functioning, the cognitive

system is proposed to be dynamic and non-linear. A key characteristic of dynamic, non-linear systems is that they exhibit the properties of chaos. When chaos theory is applied to learning in this way the result is that the nature of the conceptual structure from science learning may be unpredictable, in addition the conceptual structure will be sensitive to the so-called 'butterfly effect' (Lorenz, 1993). The 'butterfly effect' refers to the sensitivity that dynamic systems have to initial conditions. When applied to a child's learning in science the model proposes that the conceptual structures undergoing change may be sensitive to the initial conditions under which the learning has taken place and therefore take different pathways. In addition, it is difficult if not impossible to identify which of the initial states may be linked to or facilitate the changes.

Luffiego, et al. proposed a number of characteristics of the non-linear dynamics of the cognitive system which include the key assumption that new information is organised around 'attractor' concepts. These attractor concepts already exist within the learner's conceptual structure. The term attractor is taken from language used in Dynamic Systems Theory and refers to the idea that within the dynamics of chemical or biological systems there is a tendency towards a final state or 'attractor'. The conceptual schemata that exist within the child's cognitive structure act as information selectors and analysers and their scope of application and explanatory mechanisms will be mediated by the attractor concepts that they contain. Non-linearity results from the interaction between the already held conceptual schema (which resist change) and the information input that causes instability and provokes change. One arising feature is that the concepts transmitted during tuition can acquire different meanings for the learner than those that are intended. Such proposals explain how children with similar initial alternative frameworks go on to learn different things (e.g. Sharp & Kuerbis, 2006; Sharp & Sharp, 2007).

In this model, the cognitive system based on the input of new information goes through stages of stability and instability during its evolution. These stages are proposed to occur as follows:

- Stage of stability – the cognitive system appears stable before the input of new information, if change occurs once this is complete the system returns to stability again;
- Stage of instability – as new and conflicting information enters into the cognitive system it disturbs the parameters that already exist. As a result the system abandons stability. This can be translated into Piagetian terms as moving away from equilibrium. When the system moves away from equilibrium it is able to reach a maximum level of instability, the resulting pattern will exhibit the qualities of chaos. The initial attractor concept is not able to anchor the new information and it branches off in order to give rise to new possibilities. Importantly, here the term chaos does not refer to disorder it just suggests that the exact nature of evolution of the concepts is unpredictable at this stage. It is within this stage that the system is sensitive to the 'butterfly effect'.

Luffiego, et al. (1994) proposed a number of features that will arise in learning as a result of considering learning through this approach:

- the reorganisation of the system may affect the whole schema or just part of it;
- as conceptual evolution takes place the schemata acquire progressive complexity;
- other subschemata are formed which also have less powerful attractors;
- the subschemata play a role in supporting the stability of the conceptual structure.

These features are proposed to make the system more sensitive to the information coming in and thus, the cognitive system can be described as propelling and facilitating its own evolution.

When adopting this perspective children's prior ideas have an important role, these are powerful information attractors that are formed early in development through internalization. Later when formal education is encountered these concepts grow

more formal. Initial notions change from being mainly perceptive to incorporate entities that are not directly observable and as the child takes part in social interaction the intuitive cognitions begin to acquire descriptive and explanatory value. Luffiego et al proposed that:

*“...instability is controlled by the biased processing of information, the strategy of predicted conformation and either the voidance of anomalous evidence or consideration of this as specific cases”. (p.309)*

Luffiego, et al. identified three types of learning taken from Rumelhart & Norman, (1978):

- accretion;
- tuning;
- restructuring.

Like others before them, Luffiego, et al. proposed that these are three different manifestations of the same conceptual dynamics. In addition it is proposed that in order to make changes the incoming information needs to be relevant, if it differs from the schema already held it promotes tuning and restructuring otherwise the process would be simple accretion. In order to understand the difference between these types of learning Luffiego et al make a two point distinction between adjustment (the processes of accretion and tuning) and restructuring (see Figure 12 for details).

Adjustment was conceptualised as the modification or reorganisation of conceptual schema on a small scale, the attractor central or nucleus from which meaning is derived remains the same. Luffiego et al proposed that this form of modification of conceptual structure is best understood as weak restructuring. Thus Luffiego's work could be seen to build on the ideas of Vosnidou and Brewer (1987) presented earlier.

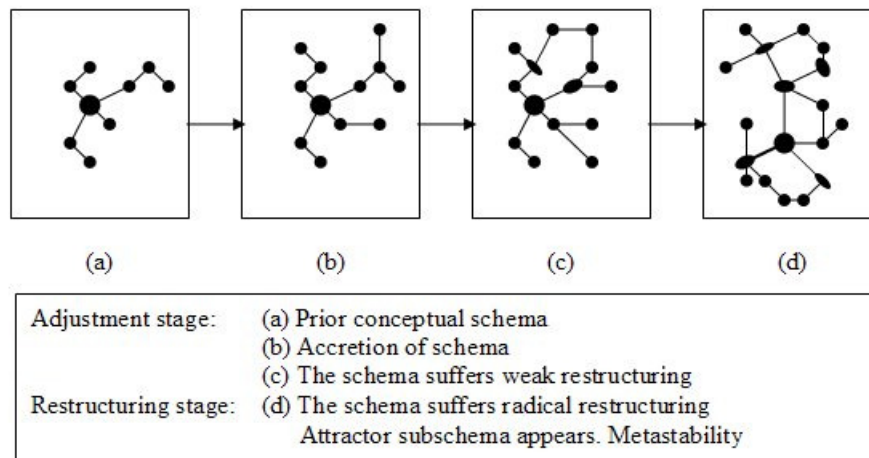


Figure 12: The different forms of change proposed by Luffiego, et al. (1994).

Restructuring, on the other hand, is a large-scale modification of the nucleus or attractor of the schema such that it is replaced by another, a process that is referred to within the paper as radical restructuring of conceptual information. As specified by Luffiego et al:

*“Therefore, the explanatory mechanisms of the schema vary; the concept meaning are either modified or they acquire a different degree of relevance within the whole system. The latter’s scope of application undergoes sizeable variations.”* (p.310)

Importantly, adjustment is a requirement for restructuring to happen and individuality in learning is explained by the view that information that may be irrelevant for some people may be amplified in others, thus timing and the results of tuition are unpredictable. As adjustment is an important prerequisite for restructuring to occur. The two processes are mutually supportive in the development of conceptual change.

Luffiego et al have not currently published any research to support their proposal but they did make clear suggestions for how this model could be tested. Two recent studies have explored learning from a chaos in cognitive perspective and provide

some support for the notions contained in this approach (Bloom, 2001; Sharp & Kuerbis, 2006; Sharp & Sharp, 2007). It could be proposed that this particular model offers more explanatory power as it combines elements of constructivist thinking with evidence.

### **3.6.4 Karmiloff-Smith's Representational Redescription Theory**

Karmiloff-Smith's (1992) approach to understanding children's knowledge growth aimed to build on Piaget's work. Like Piaget, Karmiloff-Smith proposed that children's knowledge growth results from an evolutionary rather than from an revolutionary process and it is argued that information is stored in the child's mind in several different ways. Karmiloff-Smith proposed that environmental input plays a vital role in the development of ideas; most notably acting as a trigger for the development of innate knowledge. Innate predispositions provide a skeleton structure that influence attentional biases towards specific stimuli. Over time, the model proposes that some knowledge becomes encapsulated and less accessible, whilst other knowledge becomes more accessible. Whilst Karmiloff-Smith agrees with the idea that some knowledge change occurs through explicit theory changes such as those proposed by Carey (1985) in her model of conceptual change, she also states:

*"But I will argue that this more obvious characteristic of human cognition is possible only on the basis of prior representational redescription, which turns implicit knowledge into explicit knowledge."* (p. 16)

In essence conceptual change occurs spontaneously and in response to the data received from the external environment. Karmiloff-Smith (1992) explicitly states that her approach is best considered to be a phase theory of learning which attempts to explain the processes of change that are used throughout the lifetime rather than a stage theory reflecting age-related sensitivities and skills. She argues that development is characterised by three recurrent phases. The first focuses on the information received from the environment, as such this phase is data driven and provides the foundation for the 'stock' of knowledge representations that an individual possesses. This first phase results in 'behavioural mastery' or successful



performance, which relates to the ability to apply the new knowledge. However, at this stage such knowledge is not available for explicit discussion. The second phase is characterised by a shift from being data driven, information being drawn from the environment, to being driven by the internal representations. In this phase the existing representation is used over and above incoming stimuli from the environment and this phase can be characterised by the development of new errors. Finally, during phase 3, the internal representations are reconciled with new data from the external environment and a balance is achieved. Fundamentally, Karmiloff-Smith proposed that:

- information is encoded in procedural form;
- the procedure-like encoding are sequentially specified;
- new representations are independently stored;
- level 1 representations cannot be related other representations (p. 20).

Once base-line knowledge has been formed this must then go through a process of redescription which enables ideas to be related to other ideas and to become more accessible to the child and available for explicit and verbal, report. What is most interesting about the approach is the underlying premise that children have knowledge that is implicit or tacit and conceptual change occurs when this knowledge is re-represented in order to transform it into a mode that is available for conscious recall. Fundamental to this approach is the idea that children have knowledge that is stored unconsciously, they are not able to report this knowledge but they do use it when solving problems. It is only by re-representing such knowledge into a verbal form that children are able to explicitly access their ideas and report them during interview or task based situations. The representational redescription theory is proposed to take place through four implicit (I) and explicit (E) levels:

- I level – information is encoded procedurally and the child has no awareness of or understanding of their actions;
- E1 – forms the basis for theories to be constructed, innate knowledge is now defined and represented internally, however, although this level contains

explicit knowledge the child is unable to explain why they use certain approaches;

- E2 – in this phase the unconscious representations are encoded into conscious representations, the child can carry out the actions but may be unable to explain why they have done so;
- E3 – this level incorporate both conscious awareness and the ability to explain this verbally.

In terms of the development of science ideas, this model proposes that children may unconsciously have an understanding of science concepts, and they may be able to successfully complete science activities, but they may not be able to successfully or fully articulate the ideas that they have because they are not mentally represented in a format which is available for this form of report. Karmiloff-Smith (1992) presented some support for her theory in her book *"Beyond Modularity"*, here she details how evidence for her approach can be gleaned from her work with children investigating knowledge of gravity and the law of torque using a series of balance scale problems. The results of this study revealed that the 4-5 year old children were able to complete the balance scale tasks easily, the 6-7 year old children struggled to balance any block other than those which had equal weights, and the 8-9 year old children were successful at completing all of the tasks. Karmiloff-Smith interpreted this evidence as showing that the youngest were using behavioural skills to complete the tasks, the mid-age children were applying their knowledge from a mental representation and this resulted in their reduced capacity to complete the task (e.g. they were ignoring the feedback from the environment and just applying their internal representations of the knowledge). Finally, the oldest children were able to fully complete the task as they were able to reconcile the theory with the feedback from the external environment. Whilst this work supported the proposals of the phases of learning it did not necessarily tap into the ideas of representational redescription. As yet studies investigating aspects of Karmiloff-Smith's theory have been sparse.

Replication by Philips (2007) and Philips and Tolmie (2007) explicitly explored whether or not changes in children's representations could be mediated by parental input, importantly they explored if children who received verbal descriptions during

the tasks could use this information to successfully re-represent their own ideas. This study utilised the same balance scale problems that Karmiloff-Smith (1992) discussed and provided children with different levels of tutoring. Over the course of three studies the authors were able to show that children who had received explicit verbal tutoring demonstrated more explicit representations in their discussions of the problems and demonstrated more advanced concepts than their peers who had not receive such tutoring.

### **3.7 Critiques of Conceptual Change Approaches to Learning Science**

The models of conceptual change discussed in this chapter help to illustrate some of the diversity that is present within the field of conceptual change research so far, however, despite the widespread appeal of constructivism and notions of conceptual change there are many criticisms that must be considered (Suchting, 1992; O'Loughlin, 1992; Derry, 1996; Marshall, 1996; Nola, 1997; Geelan, 2006; Niaz, 2008; Mercer, 2008). This chapter now turns to a discussion of some of these criticisms. Fundamentally, despite its widespread appeal, constructivism is not without criticism of both its application and its bias towards 'meaningful' learning (Ausubel, et al., 1978). In one paper, Millar (1989) suggested that the view of learning had been invalidly associated with a constructivist model of instruction that does not follow logically from the view of learning. Driver (1989) had previously suggested that by making children aware of their conceptions and introducing conflict it may be possible to support the construction of new ideas (also see Bell, 2005, for information of pedagogies developed from constructivist research). However, there is limited evidence that such teaching methods are effective (see Matthews, 2003 and Matthews, 1994 for a critical analysis of such views) and Osborne (1996) suggests that Driver's view lacked clear guidance. Airasian and Walsh (1997) warn that the application of constructivism is particularly challenging. Constructivism does not translate so easily into classroom practice, nor does it form a substantial basis for pedagogy. Matthews (2003) extends this criticism by suggesting that because teachers adopt constructivism they ignore other teaching approaches for which research support exists. This worrying trend in education is echoed in Taber's critical paper (2006). Taber proposes that the constructivist view

is so widely accepted that statements adopting this perspective directly influence the curriculum and standards documents produced for English schools despite a lack of appropriate research in this area (see Matthews, 1994 for a critical discussion of constructivism in relation to curriculum issues).

Despite Driver's claim of Children as Scientists, Osborne (1996) warned against this metaphor and stated that it is important that children learning school science should not be confused with 'leading edge' scientists, as they work and think in different ways, for children they are developing existing knowledge and skills whilst 'leading edge' scientists are developing new knowledge and skills. Notably, children are not being taught to construct new scientific knowledge but to acquire the existing science knowledge that is incorporated into the curriculum. In addition, Osborne suggested that the boundaries of constructivism remain untested and that the conceptual complexity of the information to be learned and developmental issues influencing attainment were often ignored. The notion of children's ideas as a coherent body of knowledge are also challenged (Millar, 1989; Solomon, 1983). Millar (1989) suggests that children's knowledge is best considered as a body of fragments whilst Solomon (1983) suggested that there are two 'worlds' of knowledge, scientific and life knowledge. According to Solomon these two forms can be contrasted and result in qualitatively different structures that are subject to context effects (also Solomon, 1987). One final criticism of the constructivist approach is that despite its powerful account for how learning takes place it neglects elucidation of the underlying mechanisms that support changes in cognitive structure. This lack of explanatory detail instigated the development of the conceptual change models as detailed above.

Conceptual change models did progress constructivist views but they are also subject to criticisms. The previous discussion considers four contrasting views of conceptual change. Each of which has a distinctly different view of the underpinning processes that support knowledge growth and highlights many of the underlying debates within this area. Some work (for example, Taber, 2008) has begun to try and reconcile these differences. Taber (2008) used learning patterns from chemistry to propose that there was evidence for the application of both Vosniadou and Brewer's perspective (1987) and diSessa's view (1988) in the same data, notably according to

Taber, students do begin by developing p-prims, it is these that are later organised into theory-like structures and then subjected to weak and radical changes following tuition. Importantly, Taber (2008) also alludes to the proposal that perhaps it depend what level of depth such learning is explored at, if the micro-level is explored then diSessa fits best. The critical discussion presented here debates the various models along with those summarised previously (table 3). Analyses of these models suggest that in many cases these different approaches appear to be capturing the same phenomena but offering different linguistic labels in order to explain their own domain-specific findings. However, these linguistic labels attributed to the conceptual change phenomena allude to qualitatively different modes of change, for example in Carey's approach (1985) the most extreme level of conceptual change is termed 'strong', whilst Vosniadou (1987) discusses 'radical' conceptual change. It could be suggested that a radical change in conceptual structure is very different to a strong change.

Whether or not the models differ purely according the linguistic competencies of the theorists' remains to be explored in detail, it could also be proposed that the different ages of participants involved, the methodologies employed, the analytical frameworks used, the interpretation and the science domains studied may also have an impact. However, it is also possible that these models differ because of the level of mental representation at which they investigate knowledge acquisition. It could be suggested that change events at theory level (McCloskey, 1983; Carey, 1985) can easily be categorised differently to the changes that occur at concept level (diSessa, 1988), these are not directly comparable forms of mental representation. The view that there may be a disparity in the levels of mental representation studies is consistent with a perspective proposed by Clement (2008). Critically, it is important to note that this problem of a lack of clarity regarding the form of representation investigated has been highlighted previously (diSessa & Sherin, 1998). diSessa deliberately outlined his own definition of a concept in order to highlight and begin debate in this area although as yet there has been little further work undertaken to reconcile these differences. It could also be suggested that the models are not comparable on the basis of their evidence, each model utilises responses from different science areas, and for example, diSessa (1988) discusses 'traditional' physics whilst Vosniadou discusses astronomy. It could be suggested that learning

in each of these concept areas is qualitatively different. These debates regarding comparability of the models limit their utility for informing teaching practices.

Additional criticism of conceptual change models challenge both their conceptualisations of the change process and discuss limitations encountered when focusing solely on cognitive processes. In one influential paper, Linder (1993) suggests that rather than conceptual change the data that is found in such studies could be reconsidered as 'conceptual appreciation'. In other research, the cognitive approach to change was challenged because of its lack of consideration for motivational variables. Although some authors including Osborne and Wittrock (1983, 1985) had previously suggested that motivation played a role in the processes of conceptual change, Pintrich, Marx and Boyle (1993) were the first authors to explicitly incorporate such variables. Pintrich, et al. (1993) reviewed a wide domain of research in order to investigate the role that four motivational constructs, goals, values, self-efficacy, and control beliefs, in conceptual change. The work built on Garner's (1990) proposal that motivational and contextual factors were likely to influence the activation of previous knowledge, and the transfer of appropriate knowledge to the current learning situation. Pintrich, et al. criticised pure cognitive models for their failure to account for what may happen if children were not motivated to change what they already knew in light of formal tuition. In their conclusion, the authors proposed that their research had raised four potential problems with conceptual change models:

- prior knowledge plays a paradoxical role in conceptual change – it can impede conceptual change as well as support it;
- the conceptual change ecology metaphor is limited as it does not take account of students' intentions, goals, purposes and beliefs;
- the conceptual change model postulates four conditions for conceptual change, dissatisfaction, intelligibility, plausibility and fruitfulness (Posner et al, 1982) but it ignores the influence that motivational constructs can have on whether or not the conditions are met;

- the validity of the metaphor of student-as-scientist assumes that the intentions of all students and classes of students are analogous, some students may not want to learn science or may not have the motivation to tackle the complexities of the subject matter.

Although Pintrich's research did not specify a new model for conceptual change, nor did it generate any new research supporting its claims, it did promote subsequent interest in the incorporation of motivational constructs into the existing cognitive conceptual change models, a research approach characterised as intentional conceptual change (Sinatra & Pintrich, 2003). This new line of research resulted in the development of 'hot' models of conceptual change (for example Dole and Sinatra, 1998). Whilst the impact of motivational factors is important this current work aims to explore the cognitive processes underpinning knowledge construction and change. Other criticisms of conceptual change research include contextual issues, for example, Vosniadou (2007) highlights that context can play an important role in the learning process and it may influence the type of information recalled. Notably, this position was previously discussed by Solomon (1987) who stated that children rely on the context of retrieval in order to decide how they will discuss their knowledge; for example, in a social situation it is highly unlikely that children will use scientific terms to discuss their ideas about the world as this would be inappropriate.

Despite strong criticisms, however, there is some multidisciplinary evidence that supports the constructivist perspective. In a pivotal paper in 1992, O. Roger Anderson presented evidence drawn from neuroscience which linked functions and structures in the brain to the processes that have been described in constructivist approaches. Anderson's work highlighted that the complex functions that occur within the central nervous system could permit learning that was based on experience. According to Anderson's research the cognitive processes of the brain such as attention, perception, short term and long memory all appear to be supportive of this view. The importance of Anderson's research was further enhanced in 2009 when he presented a neurocognitive theory of science education. In this pivotal paper presented a model of information processing which was based on a large corpus of neurological evidence, Anderson also highlighted approaches

that could be taken to enhance science learning. Anderson's Model is based on the following principles:

- knowledge is actively created through interaction with sensory experience and is in part unique to the cultural and educational history of the individual – active construction takes place by relating new information to pre-existing information in memory;
- knowledge construction is mediated through social dialogue whereby linguistic communities, often with a common cultural heritage, share information thus arriving at a consensus explanation of experiences and sensory phenomena;
- while logical proposition can be evaluated as true or false, the merits of constructed knowledge are judged by how well it promotes adaptation and survival in a given environment;
- learners are not merely shaped by our environment, but are active participants in defining who they are through building explanations of themselves, their communities and the natural environment surrounding them (Anderson, 2009).

Importantly, Anderson proposed that in order to support the children in constructing new ideas teaching should aim to incorporate the principles defined above whilst paying attention to factors related to brain function such as short term memory load, and attention mechanisms.

Whilst Anderson's model reflects the impact of neurological research and the support that it can offer to the constructivist perspective, Roth (2000) has recreated constructivist learning in computer-generated neural networks. Neural network research attempts to recreate brain processes by using computer modelling to represent neurons firing in the brain. According to this research learning and knowledge in the brain is characterised by the simultaneous firing of neurons, the more that the neurons fire at the same, the more likely they are to wire together (Robertson, 2000). This wiring process builds relationships between the neurons which are thought to represent the ways that ideas and concepts become related in the brain of the individual. Using simulations from neural network studies, Roth



(2000) concluded that the research supported the constructivist perspective and that learning occurs through typical experiences. Roth's model of constructivist learning is summarised as follows:

- knowledge is not simply stored – knowing is enacting – learning is activity dependent – learning occurs as the cognitive system engages with the thing to be learned;
- knowing is situated – learning influences perception – this leads to different perceptual experiences for each learner, different learning starting points and different trajectories.

According to Roth there is evidence that cognition cannot be thought of as something that just occurs in the head of the individual, instead it is an interaction. Thus, cognition is to be understood as a complex dynamic arising from the structural coupling of the system and the environment. According to Roth, children's ideas develop through the process of conceptual change which is slow and the changes occur along multiple dimensions. Roth proposes that such conceptual change takes place through two processes: conceptual redeployment where shifts between already existing conceptions occur and conceptual discontinuities which are relatively rare.

Thus whilst constructivism and its proposals can be debated, there is significant evidence that the overall claims of the constructivist approach have received significant support not only in science education research but also in neurological studies of the brain and simulations of brain processes during learning.

### **3.8 Discussion**

This chapter reviewed the contemporary constructivist view of Rosalind Driver. It was proposed that for the first time, the status of children's ideas had been raised and an appreciation was beginning to emerge regarding the importance of science educators' understanding of these ideas if teachers were to effectively support

instruction. Driver's work was instrumental in generating interest in children's ideas. During this time the first of a series of important science education research projects was being established some of which she led. These influential projects together with the body of studies exploring children's ideas about electricity and floating and sinking formed the foundation of how children's knowledge acquisition and concept learning changes over time. This led to the development of a new and innovative line of enquiry which aimed to map how such conceptual changes occurred. Four of the resulting models of conceptual change were reviewed in this chapter. Whilst it is acknowledged that there are many more to consider these four appear to be the most popular and representative of the diversity of approaches reflected in the literature. A critical appraisal of these different approaches was presented together with a number of reasons why so many models had arisen. These included differences based on the science topics studied, the age and educational level of the participants in the research projects, and the disciplinary biases of the researchers. Finally, in order to evaluate the constructivist perspective, this chapter addressed some of the key criticisms of constructivism and conceptual change.

What seems clear is that a conventional method of study for identifying children's ideas and mapping the changes within them became popular in the body of literature reviewed. The work reviewed in this chapter therefore acts as a foundation for the development of the research project undertaken for this thesis. The body of evidence exploring children's ideas about electricity and floating and sinking were fundamental for informing the design of the main research phase (see Chapters 4 and 5). The work in this thesis aims to build on this research foundation but it also adopts a more social approach to understanding how changes in children's ideas occur as well as attending to a multimodal approach in which a different range of response types will be measured (see later discussion). One of the criticisms of the constructivist approach is the tendency to lean towards language and language-based responses. These issues will be addressed further in the next two chapters. In addition there are clear ontological and epistemological considerations to be addressed. Ontologically, it is clear from the diverse body of research that children's ideas for different science concepts are important. Epistemologically, children's ideas can be identified and categorised according to their content and this can help to reveal how their ideas

change. In the next chapter the methodology and overall design of the research undertaken for this doctoral level work will be introduced.

## **Chapter 4 Methodology 1: Overall Design and Other Considerations**

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### **4.1 Introduction**

In this chapter the overall design and general methodology of this thesis are introduced. The literature focusing on constructivism in science education was presented in Chapters 2 and 3. In these chapters the underpinning theoretical and philosophical assumption that children are active constructors of their own knowledge was deliberated. From the literature reviewed it is clear that this approach to understanding learning has been adopted in science education and most educators in contemporary science education research now accept a constructivist approach as central to appreciating the factors that impact on teaching and learning. From an ontological perspective it was clear that children's ideas are important. They are fundamental to both teaching and learning and because of this epistemological assumptions regarding whether these ideas can be categorised were discussed. One interesting finding from the literature review was the dominance of both single and multiple-method techniques for eliciting children's ideas in order to map the ways that these may change either over time or in response to tuition. However, whilst this work has been useful for supporting understanding, as yet few studies have explicitly aimed at capturing the moments of change in children's ideas. Rather they aim to capture the changes in ideas after they have happened post-hoc. This gap in the research emphasises that as yet the actual processes and mechanisms of change are still uncertain as there is no clear, moment by moment mapping of change as it occurs. This research is explicitly designed around an approach that aims to explore the following research questions:

- does a multimodal analysis of verbal and non-verbal communication facilitate a better understanding of children's ideas in science?
- can such analyses be utilised in order to explore and contribute to an understanding of the dynamics of conceptual change?

- do the outcomes from the work in this thesis have any classroom application?

As previously suggested an overarching question is also proposed regarding whether it is possible to apply a multimodal lens to the issue of conceptual change in science education. In addition this work develops a method and an analytical framework which is designed to capture such moments of change. As previously stated Chapter 1 these research questions also propose an overarching question regarding whether or not it is possible to apply the multimodal research lens to the issue of conceptual change in science education.

The importance of method is addressed using traditional approaches to studying children's ideas. These approaches are critiqued using findings from a recent pilot study which will be discussed in more detail later in this and the subsequent chapter. Ideas from a multimodal research perspective and a subsequent discussion, evaluation and critique will demonstrate how the multi-method approach used throughout this work was developed. As with all research projects, the current work requires introduction, description, justification and critique of the methods adopted in order to explore children's ideas. Hitchcock and Hughes (1995) supported the view that the methodology associated with any research is of fundamental importance. The methods chosen influence any study or project and impact on the later decisions taken with regard to analyses and interpretation. This chapter discusses the most frequently used methods for collecting data in children's ideas research and critiques these in light of other research findings. This critique demonstrates that although contemporary research has significantly developed our understanding of how children's ideas for science emerge and evolve, there is still the potential to continue to develop our understanding if we attend to children's responses in a more holistic manner. In order to continue to drive science education research forward it is proposed that by developing a new methodological approach, notably a multimodal, task-based approach, which facilitates such a holistic understanding whilst maintaining the context of the science classroom, we may be able to further inform the current debates on conceptual change as discussed in Chapter 3. The results of a recent pilot study are used to exemplify the development of this new method as well as to illustrate the utility of this evolving methodology and its analytical framework (see Chapter 4).

## **4.2 Ontological and Epistemological Perspectives**

The epistemological and ontological assumptions of the researcher can have a substantial influence on the way in which the research project is designed and the type of questions that the researcher aims to explore (Gilbert, 2001; Cohen, et al., 2011; Arthur, et al., 2012). According to the work reviewed here already there is clear evidence of the ontological validity of children's ideas, and this research field is well established having resulted in the epistemological assumptions regarding the presentation of children's ideas and the way that these can be captured. Ontology in science education has been defined as the assumptions made by the researcher regarding what it is possible to know about the world (Gilbert, 2008). At its most extreme, ontology can be explored through the dichotomy between positivist and interpretivist perspectives (Gilbert, 2008). The positivist view supports the notion that the aim of research is to extrapolate general theories about the world by testing boundaries and hypotheses, which can then be generalised to whole populations. In contrast, the interpretivist view supports the notion that it is only possible to capture meaning which is local, within a historical context and contingent to the research participants (Gilbert, 2008). The ontological assumptions of the researcher can have a significant impact on the type of design that is adopted in order to undertake research, however, as Gilbert (2008) warns researchers' ontological and epistemological beliefs do not necessarily map to specific research methods. Whilst ontology focuses on what it is possible to know, epistemology focuses on assumptions about the nature of that reality and brings into question whether or not the external world is stable and measurable or subject to individual interpretation and developed through social interaction and collective understanding (Gilbert, 2008). Epistemology, sometimes referred to as the theory of knowledge, addresses issues about what knowledge is and how it is acquired.

The same ontological and epistemological debate can be applied to the research detailed here. The constructivist perspective used as a foundation for this work asserts that knowledge is personal construction that is based on experiences with the world, however, such knowledge construction also has social elements which are important as they guide the construction of knowledge and facilitate mutual

understanding (Driver, 1995). Firstly it can be questioned whether children's ideas hold any ontological significance at all. The research to date would appear to build a strong case that supports the view that children's ideas do have ontological significance and indeed by assessing these ideas it is possible to observe and chart children's development (see Chapter 3). In addition, as this thesis also explores the importance of children's gestures, it can be debated whether such incorporation (e.g. the analysis of gesture) is appropriate to the research design. Ontologically it can be questioned not whether gestures exist at all, as they clearly do, but whether gestures contain meaning and value for permitting access to children's underlying ideas. Epistemologically it is possible to question how a researcher can access gestures, whether gestures contain any evidence of children's ideas at all, and how any analyses addressing gesture can be interpreted for meaning. Ontological and epistemological debates aside, previous research has presented a strong case for the existence of gesture and for the ability of researchers to tap into this communication strategy in order to identify something about the knowledge and ideas that children have (Crowder and Newman, 1993; Crowder 1996; Goldin-Meadow, 2000; Roth and Lawless, 2002) a more detailed discussion of gesture will follow in the next chapter. Thus it is proposed that gesture is worthy of consideration and study.

Whilst the philosophical debate between ontological and epistemological perspectives continues to promote argument and dogmatic approaches to research design, it has also been suggested that it is perhaps better to focus on research as a craft rather than a reflection of philosophical beliefs (Gilbert, 2008). Adopting the research-as-craft approach supports the view that methods should be adopted because they are appropriate means of achieving the research aims and Mercer (2005) provides an example of this approach in practice. This pragmatic and balanced or pluralistic approach draws on positivist and interpretivist insights forms the foundation for the current research. Furthermore this approach draws on both quantitative or normative and qualitative or interpretive research paradigms.

Whilst pragmatism as an approach is also debated, Mertens (2003) discusses issues related to the provision of satisfactory answers and the individuals for whom these apply (Johnson & Onwuegbuzie, 2004). The current approach aims to make the research useful to others (e.g. teachers and researchers) working in an educational context by exploring the multimodal manner in which children express their

knowledge. Here it is important to note the differences between multimodal research and multiple-method approaches. Multimodal research aims to explore the different modes of communication that are used and the different affordances that each has for reflecting knowledge (Jewitt, 2011) whilst multiple-method approaches tend to use different approaches to research such as the collection of drawing, verbal discussions and activities in order to triangulate the findings for consistency (Arthur, et al., 2012). The current project adheres to a contingency theory that accepts that all methodological approaches exhibit some superiority under different circumstances (Johnson & Onwuegbuzie, 2004). Thus, this research aims to take advantage of the strengths of different methodological approaches in combination in order to approach explorations of children's scientific understanding from multiple levels that include children's approaches to working scientifically as well as their verbal and non-verbal responses to questions designed to probe existing knowledge and activities that are designed to challenge their ideas. Reported here is a developing methodology that maintains the researcher's reflexivity to explore arising features of children's understanding.

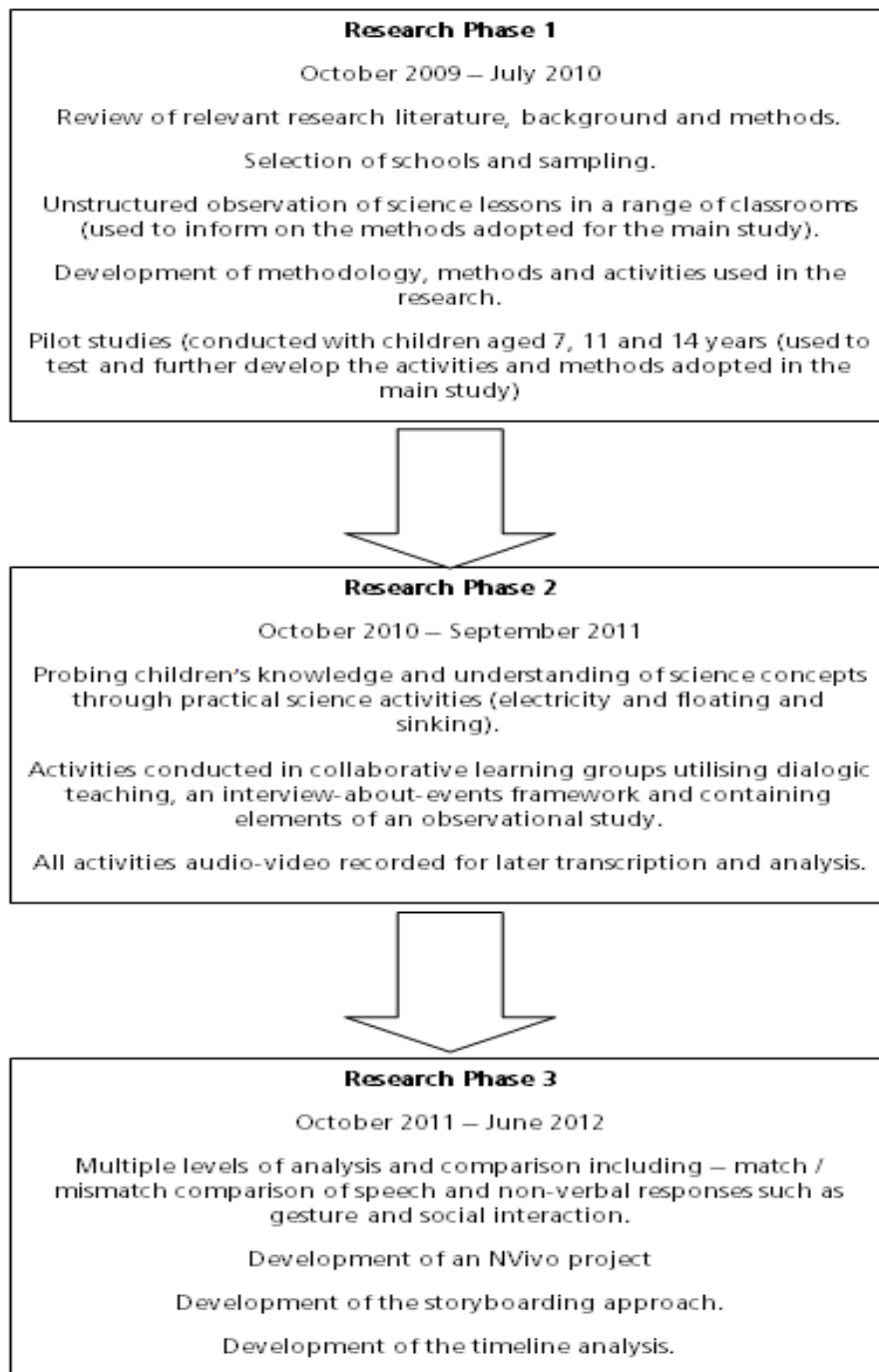
### **4.3 Research Design**

Design is the blueprint of all research (Kerlinger, 1969) and is a fundamental ingredient of any research project which can significantly influence the reliability and validity attributed to it (Gilbert, 2001). This work is designed in three distinct phases (Figure 13). This diagram acts as a road map to the proceeding sections within both this and the subsequent methodology chapter. The first phase of research consisted of reviewing the relevant literature (Chapters 2 and 3), exploring methods and methodology (Chapters 4 and 5) and used open observations of science lessons in a range of selected schools, both at primary and secondary levels. The purpose of the open observations was to gain an understanding of typical teaching approaches used. It was anticipated that these observations would help to plan activities that were as close to typical teaching sessions as possible, this was in keeping with one of the fundamental aims of the research, notably that it endeavoured to represent children's actual learning environments as closely as possible in order to keep the work environmentally valid. Once the observations were completed two activities were designed (see later section for further details). These activities were then



piloted in three schools, again at primary and at secondary levels. The audio-video recordings of the pilot study sessions were transcribed and analysed (see Chapter 5 for a more detailed discussion), this data was then used to further develop the planned sessions for research Phase 2 and to inform on the subsequent analysis in Phase 3.

Whilst there was clear guidance from the available literature as to how the interviews and observations could be used, the multimodal aspects were novel to this type of study and therefore this aspect required extensive piloting. The pilot studies were used in order to assess whether or not a study of gesture would provide a fruitful research approach and what, if anything, this might add to the field. The preliminary results of the pilot phase were subsequently published in "*Primary Science*" (Callinan & Sharp, 2011a) and presented at conferences in 2011 (Callinan & Sharp, 2011b, 2011c, 2011d).



*Figure 13: An overview of the three research phases at the heart of the study.*

Research Phase 2 comprised probing children's ideas about electricity and floating and sinking using the multimodal, task based approach (see later section for further details on this approach and participants in the studies). All children completed two activities, one in each domain. The activities were undertaken in groups in order to facilitate collaborative work between the children (Howe, et al., 1990) and all activities were video recorded to permit later analysis. Finally, in Research Phase 3

the data from Phase 2 were transcribed. Transcripts, some still images from the video recordings and children's drawing were coded using the NVivo 9 software programme in order to permit data tracking. To support exploration of how different levels of communication contributed to facilitating understanding of children's ideas an original and innovative storyboarding approach was developed and in order to analyse for changes in children's ideas a timeline analysis for the ideas and concepts that children discussed was developed significantly extending the work of Givry and Tiberghien (2012). A full review of each of the research phases will follow in this chapter and appear in Chapter 5.

### **4.3.1 Sampling and Participants**

In this section details of the sampling procedure and participants involved in the research process across the three phases are discussed. It is common in educational research for samples from the population to be studied rather than the whole population. Studying specific samples overcomes the difficulties of cost, time, accessibility, and volume associated with population wide studies but characteristics of the sample studied can have a fundamental effect on the representativeness of the data when the results are generalised (Travers, 1969; Kerlinger, 1969). Denscombe (2003, Cohen, et al., 2011; Arthur, et al., 2012;) suggest several points that must be addressed when conducting small-scale research projects and these include issues related to representativeness and the ability to draw inferences. Sampling processes themselves occur across two forms:

- probability / random sampling – all members of the population have an equal opportunity of selection in the final sample;
- non-probability sampling – where naturally occurring groups or clusters of individuals are studied.

Probability sampling was beyond the scope of the current study therefore a non-probability clustering sample method was utilised (Denscombe, 2003). In the work undertaken for this thesis the schools were identified as naturally occurring clusters of children. The schools selected to take part in the study were not random but based on the interest of the head teachers and teachers to take part in the research

project. Such convenience, opportunistic or purposive approaches to recruitment (Denscombe, 2003; Arber, 2001) are advantageous as they ensure that all parties are committed to the research process and they enable effective relationships to be formed between the researcher and the participants. However, whilst this convenience or opportunistic approach facilitates access to participants it limits the probability that all population parameters have equal participation opportunities. In addition it can be suggested that recruitment based on the interests of the head teachers and teachers can introduce bias to the sample and distort the results to the study particularly if only high performing schools agree to take part. Debates aside however, after careful consideration such recruitment was deemed the most appropriate because of the level of access to participants that the researcher needed. The subsequent section presents full details of the schools and children who participated across the different stages of the research project, however, it is noted that data drawn from documents such as Ofsted reports does suggest that the schools were not unusual in terms of location, buildings, resources or pupil attainment.

As described in the overview of the project presented in Section 4.3 of this chapter the aim of Research Phase 1 was to observe current classroom practice during typical school science lessons. It was anticipated that this stage would enable the researcher to develop an understanding of suitable teaching strategies for the research. The researcher attended a number of science lessons at a range of local schools. This included the following:

- two infant schools (including City Infant School where two lessons were observed and a second infant school where four lessons were observed);
- one junior school (two lessons observed);
- one primary school (Village Primary School - four science lessons observed);
- one secondary school (City Secondary School - a total of ten lessons were observed, these included input to Year 7, Year 8, Year 9, Year 10 and a BTEC class);

- one secondary school science club (City Secondary School – the researcher subsequently attended the club once every week for the duration of the research contained in this thesis).

Observations were conducted during the 2009/2010 academic year. The observational element of the study was conducted with the consent of the head teacher or the school liaison for university students attending the school and the class teachers. The observations included a wide age range of children, the youngest group observed were a nursery class who were studying living things and growth, and the oldest group were a BTEC forensic science class conducting an assessed practical testing a variety of liquids for the presence of sugar. All observations were conducted using an unstructured approach, e.g. the researcher entered into the sessions with the intent of exploring the organisation and management that teachers used in the classrooms, the children's responses to the tuition, the way that practical activities were used to support teaching, typical classroom layouts, and grouping procedures. In all instances the researcher was able to discuss the structure, aims and planning for the lessons with the teachers prior to participation. Wide ranges of science topics were observed including biology, chemistry, physics, and forensic science. Specific lessons included a Year 6 primary school lesson on climate change which explored the impact that such changes might have on wildlife (e.g. the polar bear) and included the design of more ecologically friendly forms of transport. A sequence of two lessons designed for Year 2 children with a focus on plant growth was also observed, during these two lessons the children learned the names for different parts of plants, discussed the function of the different areas and had the opportunity to grow their own plants from seeds. The observations were used in the subsequent planning of the science activities used as a focus in the pilot studies and Research Phase 2, to familiarise the researcher with the organisation, managements and assessment techniques used during teaching and learning to work with the different age groups of children, and no further discussion of these will be presented here.

In order to complete the pilot studies, three schools were recruited as indicated. All three schools were drawn from the sample where the unstructured observations had taken place.

**City Infant School** (not the school's real name) was a small infant school in a mid-sized city in the East Midlands that was voluntarily controlled by the Church of England. It accommodated a mixed gender of children between the ages of 4 and 7 years and had an above average proportion of pupils who came from minority ethnic backgrounds. At the time of the study the school had 87 pupils in total across the three different year groups, Reception, Year 1 and Year 2. The school had four qualified teachers and five teaching assistants. According to the 2009 Ofsted report, the school was rated as having an overall effectiveness of 1 and a foundation stage effectiveness rating of 2. The attainment figures for 2012 show that 100% of pupils attained Level 2 or above in their Key Stage 1 reading assessment; 100% attained Level 2 or above in mathematics; and 96% attained Level 2 or above in writing assessment.

**Village Primary School** (not the school's real name) is located rurally in a small village close to a mid-sized city in the East Midlands. The school is an average-sized primary school that was controlled by the local authority. It accommodates a mixed gender of children between the ages of 4 and 11 and the majority of pupils are of white British heritage. At the time of the study the school had 210 pupils across the year groups, Reception to Year 6. The school had 12 qualified teachers, including the head, and 9 learning support assistants. The proportion of pupils in the school claiming free school meals was lower than the national average. According to the 2011 Ofsted report, the school had an overall effectiveness rating of 2 and a foundation stage effectiveness rating of 2. The attainment figures for 2012 showed that 86% of the children attained Level 2 or above in their Key Stage 1 reading assessment; 90% attained Level 2 or above in mathematics; and 86% attained Level 2 or above in their writing assessment.

**City Secondary School** (not the school's real name) was a larger than average secondary school located in the suburban area of a mid-sized city in the East Midlands. The school was a specialist language college and had a growing sixth form. It accommodated a mixed gender of children between the ages of 11 to 19. Approximately 8% of the pupils were from minority ethnic backgrounds. At the time of the study the school had 1,685 pupils including the sixth form. The school had a large number of teachers and pastoral support staff. The school had a below

average number of children receiving free school meals but drew its pupils from some communities with significant social disadvantage. In 2012 the school converted to academy status and was pending an Ofsted inspection. The published results for 2012 showed that 53% of pupils attained 5 GCSEs at grade A\* to C (including mathematics and English). 66% of pupils attained English GCSE at grade A\* to C; 63% of pupils attained GCSE mathematics at grade A\* to C; and 42% of pupils attained GCSE science at grade A\* to C.

The following participants were recruited from these schools for the pilot studies:

- 7 children in Year 2 (3 boys, 4 girls) from City Infant School;
- 10 children in Year 2 (7 boys, 3 girls) and 10 children in Year 6 (7 boys, 3 girls) from Village Primary School;
- 11 children in Year 8 (4 boys, 7 girls) from City Secondary School.

In order to complete Research Phase 2 participants were recruited from Village Primary School discussed above; in addition participants were also recruited from the following additional schools:

***Village Secondary School*** (not the school's real name) was an average size secondary school also located rurally in a small village close to a mid-sized city in the East Midlands. The school was a small, specialist sports, maths and computing college. At the time of the last Ofsted inspection there were 506 pupils on roll, all between the ages of 11 and 16 years. The majority of the children who attended the school were White British. Attainment was below average on entry to the school. On site was a small specialist unit for students with hearing impairment. At the time of the research the school was in a period of transition with a new head teacher coming into post. In addition, in 2007 the school joined with six other secondary schools to share staff, specialist resources and governors. According to Ofsted 2012 attainment data, 60% of the pupils attained five GCSEs including English and mathematics at grade A\* to C; 82% of the pupils attained English GCSE at grade A\* to C level; 67% of pupils attained GCSE mathematics at grade A\* to C; and 53% of pupils attained GCSE science at grade A\* to C.

***City Independent School*** (not the school's real name) was a privately funded independent school which was part of the United Church School Trust (UCST). The

school had three sites in a mid-sized city in the East Midlands area of England, it also had 'sister schools' in two other cities. The school employed over 80 teaching staff members and a generous number of support assistants, it caters for children from 2 to 18 years and according to the school website it accommodated 900 students across its three sites. The school offered a full time boarding option and charged fees, although some children were funded through scholarships and bursaries. The inspection process was different in schools of this type and was provided by the Independent School Inspectorate. At the time that this work was produced only one report was available and this was for the older children who were not directly involved here. However, the school GCSE performance figures for 2012 showed that 90% of children attained 5 GCSEs including mathematics and English at grade A\* to C. Whilst it could be argued that the children recruited from this school were not representative of the local population, it is proposed that the addition of this sample alongside the mainstream school participants does in fact enable the study to more clearly represent all aspects of the population in the region.

The following numbers of children participated in Research Phase 2:

- 19 children in Year 2 at Village Primary School;
- 15 children in Year 2 at City Independent School;
- 28 children in Year 6 at Village Primary School;
- 16 children in Year 6 at City Independent School;
- 15 children in Year 9 at Village Secondary School.

No additional participants were recruited for Research Phase 3 which focused on analysing data.



### 4.3.2 Ethical Considerations

Bulmer (2001) defines ethics as “*a matter of principled sensitivity to the rights of others*” (p.45). This principled sensitivity must underpin all research projects and often impinges on the ways in which research can be conducted. Central considerations include issues such as obtaining informed consent, respecting privacy, safeguarding confidentiality of data, possibilities of harm to subjects and researchers, decisions regarding the use of deceit in order to obtain data and the consequences of subsequent publication (Bulmer, 2001). These central considerations were attended to when planning the research described in this chapter, however, in addition other ethical issues were considered as deserving extended consideration in the current study, one such issue included the age of the participants (Cohen, et al., 2011; Arthur, et al., 2012). A number of ethics policies including those of Bishop Grosseteste University (2008), the British Psychological Society (2010) and British Educational Research Association’s ethical guidelines (2011) were used to guide the research process at every stage. In addition, the current legal requirements for adults working with children and vulnerable people were adhered to and reference was made to published materials that aim to guide researchers in conducting ethically sound research (Bulmer, 2001; Banks, 2007). In the first instance, the researcher attained a Criminal Records Bureau disclosure in order to demonstrate suitability for working with children in schools. As safeguarding children is a consideration that all schools must make the researcher completed a Safeguarding Children training course to help ensure that appropriate practice was observed at all times. Finally, ethical approval for the study was obtained from the university and a number of steps were taken in order to protect all parties concerned. These steps included:

- supervised contact with the children in familiar areas of the schools;
- the provision of appropriate levels of information to all parties;
- adherence to health and safety policies (including those proposed by Association of Science Education);
- informed consent was gained from all parties including the children;
- no feedback on children’s performance was given to the schools;

- data generated were stored securely on an encrypted external computer hard drive that only the researcher held the password for.

One particular issue arising from the planned study was the use of audio-video recordings. Extensive consideration was given to how to store and subsequently use these materials. Banks (2007) stated that:

*“...all social researchers agree that unless there is a strong justification for doing otherwise, the social researcher has a duty to protect the privacy of the research subject.” (p.86)*

This particular aspect of the work was given extensive consideration and in all cases participants, participants’ parents and schools were asked for permission to use images where a child was identifiable. Attempts were also made to blur the children’s faces sufficiently so that identification is not possible on the images that were used.

#### **4.4 Research Phase 1: Pilot Studies**

In order to fully develop the methods to be used in the Research Phase 2 of this project a number of pilot studies were undertaken. The pilot studies were particularly important because they were used to develop effective techniques for capturing the data required, for developing the researcher’s skills in working with the children, and for developing opportunities to challenge children’s existing ideas in order to elicit change. In order to develop an effective approach to undertaking the pilot studies it was considered important to review the typical approaches that had been used to study children’s ideas in science particularly as this project aimed to build on the extensive previous background work (for example Bell, 2005; The Primary SPACE Project Reports, 1990-1998; Osborne & Freyberg, 1985; CLIS, 1984; LISP, 1979-1996). Many methods of data collection had been used to explore children’s ideas and concepts in science including, but not limited to, interviews (Vosniadou & Brewer, 1987), children’s drawings (Sharp & Kuerbis, 2006), and observation (Tasker, 1981). Whilst each of these approaches clearly has its strengths it is

proposed that each of these methods in isolation is insufficient for capturing the depth required in order to conduct the multimodal analysis that this work aims to achieve. In this section these important research methods are briefly reviewed and discussed in relation to how these have shaped the design used throughout the research undertaken here.

#### **4.4.1 Research Methods – Interviews**

Interviews are considered to be the oldest and most frequently occurring method for obtaining information (Kerlinger, 1969) and these are functionally defined as conversations with a purpose (Cannell & Kahn, 1968); that is to collect information regarding the views, opinions, perceptions, attitudes, preferences and behaviours of interview participants (Cohen, et al., 2011). Cannell and Kahn (1968) further describe the interview as:

“... two person conversations, initiated by the interviewer for the specific purpose of obtaining research-relevant information, and focused by him (sic) on content specified by research objectives of systematic description, prediction, or explanation”. (p. 527).

Kerlinger (1969) stated that interviews offer a direct route to data collection, a characteristic that can be perceived as both a strength and a weakness of the approach. Interviews can take many forms (Cohen, et al., 2011; Arthur, et al., 2012). They can focus on an individual or take place in groups, they can be highly structured containing closed questions or unstructured where the interviewee has control of the final direction that open-ended questions take. Despite the diversity offered by this method, the most frequently used form of interview in science education is one-to-one and in a semi-structured format. The advantage of this is that the interview is perceived as being shared between both the interviewee and the interviewer. The semi-structured format also permits the interviewer to use a mixture of questions and retain the freedom to follow-up on specific points that may arise during data collection. In addition to questions, the research interview can also

include practical and intellectual tasks as demonstrated by the SPACE project (1990 - 1998) and LISP research projects (Bell, 2005).

A research interview has a number of processes and conditions attached to it that are crucial if the method is to be successful at illuminating the information relevant to the research questions. According to Cannell and Kahn (1968) the processes of research interviewing can be defined as follows:

- creating or selecting an interview schedule;
- conducting the interview;
- recording the responses;
- creating a coding system (defined by Cannell and Kahn as a numerical code, however, in qualitative research terms it is more effective to use themes in order to code content);
- coding the interview responses;
- analysing data.

Importantly, it may also be advantageous to add a further process, that of accurate interpretation. Interpretation of linguistic data has a fundamental impact on the results of interviews particularly as verbal responses to interview questions have tended to dominate approaches to understanding children's scientific knowledge (Lythcott & Duschl, 1990). In one critical paper, Johnson and Gott (1996) warn that although interpretation of interview data may appear to be straightforward there can be difficulties especially when the interview participants are children. Fundamentally, it is proposed that the words that children use may be interpreted in an entirely different context when investigated from an adult perspective. This was suggested to occur because adults and children do not exhibit the same interpretations of linguistic data (a later discussion in Section 4.7 returns to these issues).

#### **4.4.2 Research Methods - Interviews in Science Education**

Lythcott and Duschl (1990) support the view that evidence regarding children's ideas is 'overwhelmingly' drawn from analyses of verbal data collected during research interviews. In science education, research interviews are established research tools with their roots in Piaget's work (1929) which used 'clinical interviews' with children in order to probe their conceptual ideas across a wide range of topics. In later work, Piaget (1960) further developed this methodological approach to include tasks with objects and this became known as the 'method of clinical exploration' (Ginsberg & Oppen, 1988). Although the validity of Piaget's approach to understanding intellectual development through knowledge growth can be critiqued, it is largely recognised that his methodological approach is particularly helpful in uncovering children's reasoning in relation to science (Osborne, et al., 1991). Interviews therefore provide a method for eliciting the understanding that children have of specific scientific concepts. White and Gunstone (1992) have proposed that there are two distinct forms of research interview that can be used to investigate children's understanding in science:

- interviews about instances and events – this form of interview is a deep probe into a student's understanding of a single concept, the aim is to investigate whether the concept is applied appropriately as well as to investigate if the student can explain their decision. Typically, this type of interview will use drawings, activities, or prompts that bring certain situations containing the concept of interest to light. Students are then asked to discuss;
- interviews about concepts – this form of interview is more frequently used in order to gain an understanding of all the ideas and facts that a student associates with a specific concept. The purpose is to elicit as much knowledge as possible.

From the research literature, the most frequently occurring form of interview in science education appears to be those with a focus on instances and events (for examples see the work of diSessa, 1988, and Driver, 1978, 1983, 1986) as these permit researchers, particularly those investigating conceptual change, the

opportunity to explore the conditions under which students' apply their knowledge. In order to guide researchers Osborne and Freyberg (1985) used their experience of working with children in order to propose a number of procedural recommendations. These included making sure that interpretations of this form of data reflect the child's meanings rather than the adults and maintaining the opportunity to explore the reasoning behind the responses that are received. The strengths and weakness of the interview approach as drawn from the work of Mathison (1988) and Lythcott and Duschl (1990) are summarised in Table 4.

<b>Strengths and Limitations of Research Interviews with Children</b>	
<b>Strengths</b>	<b>Limitations</b>
Flexibility - it is possible to incorporate many different activities at the same time, including but not limited to drawing, selection activities, and identification tasks.	Mastering the technique of questioning children is complicated.
Direct method of collecting data. Richness of the data obtained.	Inducing child conversations is a difficult task, adult interviewers are perceived as authority figures and this can prevent children from entering into conversation as they normally would.
Depth of detail that researchers can uncover.	Children's responses can be misrepresented.
Possible to interview more than one child at the same time, group consensus can have advantages for research aims.	The researcher needs to remain tentative in their hypotheses of what the child knows in order to adapt to the flow in the child's conversation.
	Where more than one interview participant is present responses can be influenced by the social context.

*Table 4: Strengths and limitations of using research interviews with children (Mathison, 1988; Lythcott and Duschl, 1990).*

As suggested by the limitations listed in Table 4 it is fundamentally important for research involving children as participants to adopt appropriate procedures for asking children questions. In order to ensure that appropriate approaches to asking questions were utilised during the current study, reference was made to a number of

educational sources (Harlen, 1995; Ollerenshaw & Ritchie, 1993). In order to prevent children feeling pressured to give an accurate response to questions, Elstgeest (1995) recommends the use of 'why do you think' and 'what do you think' questions. It is proposed that by structuring questions in this way, the onus for providing factual responses is reduced from children. In addition, when researchers also specify that it is okay for children to say that they 'don't know', pressure for responses, whether accurate or not, is removed from those who may not be able to introspect on the sources of their own knowledge. Elstgeest (1995) also suggests that when questions are complex, children can be assisted in dealing with these if the questions are broken down in manageable steps. This advice was adopted during the current study with most questions being framed in a 'why do you think' or a 'what do you think' manner.

Despite the limitations of the interview method and with the provision that the researcher remain mindful of the possible ways in which data obtained in this way can be subject to 'contamination' it was anticipated that the current research would utilise an interview about instances and events approach in order to investigate children's conceptual knowledge whilst they complete scientific tasks and was built into methodology and piloted. However, in order to maintain a high level of ecological validity, or validity that most accurately represents the school learning environment, this research moves away from the traditional individual interview and investigated understanding as assessed in a group context. There are key advantages to using group context. The following extract from the pilot study conducted here demonstrates one way in which children can support each other when answering questions if one participant is uncertain about what to say (RS = researcher).

Time	Person	Verbal Report
	RS	Ok, so I would like you to have a think for me about things that float and things that sink, ok (pauses) right, ok, so what do you think floating is?
0:34	Tom	Something that doesn't go under water
	RS	Ok
	Julie	It rises above the surface
	Steven	Erm, yeah
0:45	RS	When you say it rises above the surface what do you mean?
	Steven	I know...
	Julie	Erm...
	Steven	It stays on the top
	Steven	And erm...its stay on top of the water

*Table 5: Excerpt from Year 8 pilot study investigating the scientific understanding that children associate with items that float and sink.*

This excerpt from a larger transcript demonstrates how the pressure on the participant to answer the researcher's question is deferred and relieved by the social support present within the group context (Table 5). This approach to the interview process also supports the children by recreating the familiar context usually encountered in the science classroom. Group interviews, sometimes called focus groups, are frequently used in research; however, they are perhaps less frequently used in science education research.



#### **4.4.3 Research Methods - Group Interviews / Focus Groups**

Group interviews are broadly similar in many respects to individual research interviews with the exception that they have more than one participant present at the same time, and interaction between participants is one of the key points of interest (Kitzinger, 1994, 1995; Morgan, 1996). Group interviews are sometimes considered synonymous with focus groups typically. The distinction between the two is based on whether the group existed prior to the research taking place, the level of interaction permitted during the process, and whether or not a researcher is present to guide the purpose of resulting discussions. Morgan (1996) suggests that a clear distinction between group interviews and focus groups is often difficult to define, especially as both methods can take place in similar settings with similar types of group formation and similar research aims. For the purposes of the current research project, it was considered that although the groups typically did exist prior to the research being undertaken, the interactive nature of the data collection and the researcher's aim to focus discussions on specific areas of interest would fulfil the criteria of focus group. Thus there are parallels between focus groups as discussed in the literature and the groups of children used for the purposes of the research in this thesis.

Focus groups are a technique for investigating the communication within groups of individuals as well as a means for understanding their individual knowledge and experiences (Kitzinger, 1995, 1994). The development of the method is accredited to Merton (1956) who employed the technique to investigate people's reactions to propaganda during times of armed conflict. In a standard interview, interaction is rarely, if ever, noted, the focus group by contrast investigates interaction between individuals and uses this data in order to understand the ways in which the social environment influences individual responses and constructions of knowledge. Traditionally, focus groups have been used in a wide variety of contexts including marketing and social research (see Morgan 1996 for an overview). Focus groups are a popular method for gathering group data and depending on the way in which these are facilitated, the approach offers a unique insight into the way in which meanings are constructed and understood within a group. Often focus groups will be combined with other approaches such as surveys and individual interviews, with

focus groups being used to validate data drawn from other sources. It is typical practice during such research sessions to complement research questions with activities that the group will undertake. Kitzinger (1994) suggested that activities undertaken in focus groups can generate “*invaluable data*” (p.107) and provide a means that permits comparative analysis between groups. In addition, Kitzinger (1994) stated that:

*“Group work ensures that priority is given to the respondents’ hierarchy of importance, their language and concepts, their frameworks for understanding the world.”* (p.108)

As with all methods, focus groups have a number of strengths and weaknesses. The most frequently stated advantage is its ability to reveal insight into the way in which social interaction influences individual participant’s knowledge; it is a possible means of tapping into meaning construction as it would normally occur. Focus groups are able to reveal sources of diversity in understanding as well as to elucidate areas of consensus (Morgan, 1996). The group context permits a greater variety of communication than can be drawn from other research methods (Kitzinger, 1994). The group context relieves the ‘burden’ of explanation participants can feel in an individual interview context (Morgan, 1996). In addition, participants in focus groups often facilitate direct comparisons within the group’s membership through their own questioning of each other’s responses. However, weaknesses of the method include the possibility that the group context may cause participants to censor their responses in order to maintain social cohesion within the group. The facilitator may unintentionally interrupt and divert the group discussions thus suppressing valuable insights. Group membership can also have a fundamental impact on outcomes (Morgan, 1996) especially when the participants know each other well. Kitzinger (1995) also warns that this method compromises the participant confidentiality that individual interviews support and this may subsequently influence the types of discussion that occur. Discourse analysis studies comparing participants’ responses in interviews and focus groups present substantial results that support this criticism of the method (Agar & Donaldson, 1995; Saferstein, 1995) and in addition they also reveal disparity between the responses of participants in a group context compared to responses in an individual setting. This suggests that

researchers need to remain mindful that responses collected during a focus group may not reveal a true representation of an individual's beliefs, knowledge or understanding.

Weaknesses aside for the moment, and, for the purposes of this research project, this approach was considered to provide an appropriate method for addressing the research questions as it would enable the participants to talk about scientific concepts within their own framework of understanding. The group context also reflects the environment typically occurring within a science classroom when practical activities are undertaken and this may in part help to resolve the difficulty associated with achieving a comparison that is close to actual environment in which children learn.

The following excerpt from the pilot study demonstrates how children interacted during discussions in science lessons, illustrating how they help each other by completing intended utterances where peers struggle to finish (Table 6). They also express contrasting views. The children participating in this activity were all in Year 6 of primary school. The group consisted of two girls and three boys, and all of the children were from the same class and were familiar with working with each other (RS = researcher).

Time	Person	Verbal Report
07:22	RS	Ok, so can you tell me what is happening in that to make the bulb light?
07:31	Rachel	Erm, the batteries are making the power go all the way, no, the electricity go all the way to make the bulb which is making it... (hesitates at this point)
07:41	Sally	Light up
	Rachel	Yeah
07:44	RS	Ok, do you agree with that?
	Sam	Is it cuz, like, on there, there's two pieces of metal like and on there and then if you like clip them on they'll...thing...like something will go through there and it connects like on the metal to there which the battery power will go through there

*Table 6: Excerpt from a pilot study of the electricity activity conducted with Year 6 children from the Village Primary School.*

In research investigating children's ideas focus groups are rarely, if ever, reported although a number of projects do specifically investigate children's knowledge elicited in a group context. One example of this type of research was presented by Bloom (2001). Bloom's study investigated children's understanding of density and the way in which these understandings change following a task based discussion regarding an unexpected occurrence (e.g. a piece of ebony sinks when the children expect it to float). Although Bloom's work was embedded in a teaching context, his method of inducing interaction through questioning is representative of focus group techniques. The subsequent analysis of group interaction and the resulting learning by the children taking part revealed the underlying experiences and understanding of the group with regard to the subject matter. It was determined from the pilot that the group based task approach would be a specifically useful approach for the Research Phase 2 and assist in revealing children's conceptions of scientific knowledge. However, although focus groups were considered valuable, there was also a requirement for the researcher to be reflexive and open to events that occur during participation in the science activities. One other aim of the research project developed here was to investigate the role that non-verbal behaviour had when children were expressing and developing their scientific knowledge and a pure focus group approach does not provide that level of detail for analysis. In order to enable this additional layer of depth it was important to consider the strengths and weaknesses of observation.

#### **4.4.4 Research Methods - Observation and Participant Observation**

Observational research methods originated from ethnographic studies (Denzin & Lincoln, 2003; Friedrichs & Ludtke, 1975). Scheuch (1958) described observational studies as follows:

*“...the recording of facts, perceptible to the senses and on the basis of a set plan in which the researcher maintains a receptive position in confrontation with the research object. This receptive position distinguishes observation from the interview and the experiment, in that one dispenses with evoking the desired reactions by verbal as well as other stimuli.” (p.5)*

Observational methods can be an effective research tool particularly if the aim of the research is to capture the dynamics and complexities of activities or events (Wragg, 1999). As with research interviews, observational studies can be conducted on many levels ranging from the researcher playing the role of a participant in the situation to remaining complete divorced from it through non-participation. In addition, observation studies can take many forms:

- structured – a clear agenda is set for what the observation will record;
- unstructured – the observer will have no agenda;
- semi-structured – the observer will have some items set out for recording but will remain reflexive to the situation in order to accommodate unexpected incidents that occur.

Each of these forms of observation has their own strengths and weaknesses (Table 7). For example; unstructured observation may result in the researcher being insufficiently focused and prevent the collection of important data (for more details on strengths and weaknesses see Table 7). Structured observation may be too inflexible to permit the observer the opportunity to record important information that may influence the behaviour that is being studied thus resulting in a distortion of interpretation. However, despite these limitations, observational studies are

particularly useful if the aim of the research is to collect information about what people actually do, it can also be an effective method for studying people's actions and interactions.

If the observation is well planned, it can offer information about the complexities of behaviour that may not be facilitated through an interview or experimental situation. Friedrichs and Ludtke (1975) described the following as four advantages of the observation method:

- it avoids the discrepancy between real and verbal behaviour;
- it allows observation in situations when questions only meet with misunderstanding or try to evoke attitudes which are first created in the interview situation; often such facts are brought to light by means of natural setting only;
- it allows the identification of processes which could otherwise only be brought out by an inconvenient change of repeated interviews or content analyses;
- the observation of behaviour does not depend on the verbal capabilities of the interviewed person. Just such class-related capabilities reduce the range of interviews, group discussions, and possibly the content analysis.

<b>Strengths and Limitations of Observation Methods</b>	
<b>Strengths</b>	<b>Limitations</b>
Captures the dynamics and complexities of activities / events.	Can be either too flexible and lack guidance or too inflexible depending on the design.
Permits the researcher the opportunity to explore arising features of interaction.	Can result in the over-simplification / trivialisation of complex and dynamic situations.
Can be used for clarification / triangulation.	Can be intimate or personal which requires ethical consideration.
Can be more open than other approach to research enquiry.	Can be value-laden.
Participant observation techniques	The researcher can unintentionally influence the outcome, participants may not

<p>permit the researcher the opportunity to fully engage with the participants.</p> <p>Avoids the discrepancy between real and verbal behaviour.</p> <p>Overcomes misunderstandings that can occur by using questioning techniques alone.</p> <p>Does not rely on the verbal competencies of the research participant.</p>	<p>behave or answer in the same way as they would if not being observed.</p> <p>Observer bias can occur in both data collection and interpretation.</p> <p>Can present a distorted picture of the interaction depending on the approach to observation.</p>
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*Table 7: The strengths and limitations of observational methods (Denzin & Lincoln, 2003; Friedrichs & Ludtke, 1975).*

Taylor (2006) demonstrated support for these advantages in her research investigating how boys use actions in order to complete and complement their discussions of sport. Taylor observed and video-recorded a conversation between a group of five boys discussing a football match. This observational study was able to reveal significant evidence supporting the notion that gestures and actions performed with the body compliment and complete communication verbalised through speech. This evidence may not have been so forthcoming if the researcher has intervened or questioned the boys using an interview technique.

There are number of techniques that are associated with successful observational studies:

- note taking – accurately recording the events that occur;
- frequency counting / tally charts – recording how many time a specific behaviour or interaction occurs;
- interval sampling – recording the events that occur within specific time intervals;
- duration sampling – recording the length of time that actions or interaction are performed over;
- activity or event rating – rating events on a scale in order to assess the effect of those actions;

- photography – capturing images that can be used in later analyses of events as they happen;
- audio-visual recording – this approach permits the researcher the ability to code the data off-line, thus events can be replayed and inter-rater reliability can be established.

Each of these techniques has their own strengths and limitations but if carefully organised they can be used effectively in a research capacity. The key weaknesses of the observational method approach include observer bias occurring in both the collection of data and the interpretation of the data and the unintended influence that the researcher can have on the behaviour of the participants even when they do not take an active role in their presence can influence how the research participants behave. Furthermore there can be issues related to the time that is needed to record the data, issues related to participants, issues related to researcher participation and the possible biases and distortion that this can introduce.

Observation has also had a significant role to play within science education research. One study by Tasker (1981), for example, used the approach to uncover the ways in which teachers' and children's interpretations of intentions during science lessons varied. In another study observational techniques were utilised in a Grade 10 class of German children in order to explore the conceptual change occurring as an understanding of chaos theory was developed (Duit, et al., 1998). The main analysis for this study was drawn from an opportunistically video-recorded discussion between five girls as they debated the behaviour of a pendulum. In order to capture the data each of the researchers observed individual groups working through the science activities. A video camera was placed in the middle of the room which was used to record the interaction once a particularly interesting conversation was observed to be occurring. The results of this study were interpreted to suggest that unwarranted conceptions could occur following practical activities even when the curriculum is well structured. However, the opportunistic results of this observational study revealed the strength of using this approach when investigating conceptual change.



In order to address the research questions presented here participant observation was employed and in order to permit the subsequent analysis all activities with the children were audio-video recorded using two cameras set at different locations in the room so that the greatest coverage of the children's activities was possible. The audio-video recording was an essential component particularly for the multimodal approach and analysis adopted in this thesis. Previous research had highlighted that conversations are just one means through which children communicate their ideas (Kress, et al., 2001) in order to gain a more holistic understanding of children's ideas and concepts it was considered advantageous to acknowledge a range of response types through a multimodal approach (a full review of the multimodal approach will follow in chapter 5). Here, therefore, the children will be observed for instances when they appear to be stuck for words or when they appear to be relying on other response types in order to complete their communication of ideas. In application to the current research, observation plays a fundamental role in the data collection, particularly as the research aims to elicit students' understanding of scientific concepts during their completion of science activities.

#### **4.5 The Multiple-method Approach Used in the Pilot Studies**

The approaches to data collection reviewed so far and used in the pilot studies highlighted that a multiple-method approach would be the most sensitive for addressing the research aims. In addition to the focus group and participant observation approaches the literature also revealed that children's drawings were frequently collected in science education research and that these often added to the researchers' understanding of the ideas that children held (for example Vosniadou and Brewer, 1987, used children's drawings to assess their ideas about astronomy concepts). In early work Symington et al (1981) discussed the importance of studying children's drawings of natural phenomena and important science projects such as SPACE (1990 – 1998) drawings were used in order to triangulate an understanding of children's ideas. It is perhaps no surprise then that when using the multimodal perspective drawings are also attributed with a role for revealing aspects of knowledge that may not be afforded to speech or written work (Kress, et al., 2001; Jewitt, et al., 2001; Kress, 2010; Jewitt, 2011). Therefore the opportunities for

children to complete drawings were also provided. It was clear from an evaluation of the evidence obtained that a single approach would not enable the researcher to tap into the children's ideas with an appropriate level of sensitivity if used in isolation. The pilot studies were designed to include elements of all of the techniques discussed above, a semi-structured focus group schedule was developed, this was applied using a dialogic teaching technique (Alexander, 2004; Fisher, 2007; Lyle, 2008; Mercer, et al., 2009; Heneda & Wells, 2010). The dialogic teaching technique had been supported by previous science education researchers because of the approaches ability to not only probe children's ideas effectively using questioning but had been shown to support children's learning because of its discursive nature in which children are able to work out their own ideas through talk in the classroom context. The elicitation of ideas took place in a group learning context provided through practical science activities, an approach that was typical of learning in all age groups in the schools observed during the unstructured observations from Research Phase 1. Practical work in science had also been highlighted to be important by many researchers and research projects (Woolnough, 1991; Kirschner, 1992; Duggan & Gott, 1995; Gott & Duggan, 1996; Wellington, 1998; Leach & Paulsen, 1999; Wickman & Ostman, 2002; Braund & Driver, 2005; Hogarth, 2005; Abrahams & Miller, 2008; Gatt, 2009; Millar, 2010; Abrahams, 2011). Notably, although the effectiveness of practical work can be debated, particularly with reference to the quality of practical experiences, there was strong evidence that direct experience of important concepts and ideas can support children's development of ideas. The researcher used participant observation in order to retain the flexibility to probe children's ideas during the activities and in order to identify when children had reached the limits of their understanding in order to prevent distress. The use of these probes was reflexive on the part of the researcher as the researcher aimed to ask the questions at moments during the activities when the children were likely to be receptive and able to answer the questions presented. Therefore, although there was a schedule for the activities and target questions that were asked of all groups, the timing of the questions as well as their content was flexible to suit each group of participants as required. The cue for adaptation was drawn from the researcher observation of the children's progress and abilities as they worked their way through the tasks. This combined application of different methodological techniques was best described by the multiple-methods approach.

However, one important criticism of all elicitation techniques was presented by Johnson and Gott (1996) who explored issues related to the interpretation of children's ideas as drawn from all such research findings.

## **4.6 Application in Context**

The pilot studies took place in the three schools identified in the participants' section of this chapter and were held during the final term at the end of the academic year 2009 / 2010. The children undertook work in two areas of science as indicated:

- electricity;
- floating and sinking.

These activities were specifically chosen because they provided for different approaches to learning, the electricity activities were practical but abstract in nature and required a greater degree of conceptual knowledge and understanding than the floating and sinking activities, the outcomes of which are perhaps more tactile and observable. It was anticipated that the contrast between the two areas; one theoretical, one inherently visual, would facilitate a greater understanding of knowledge growth. In addition, both of these areas of science were part of the National Curriculum (electricity appears in 'physical processes' and floating and sinking appears in 'materials and their properties' but can overlap with the 'physical processes' input at secondary level). These two areas are familiar and easy to undertake in practice and it was anticipated that all of the children may have had some prior contact with these areas. In addition, the previous research (detailed in Chapter 3) has revealed that both areas were rich sources of alternative frameworks of understanding.

The two activities were designed to last approximately one hour each, although in general the electricity tasks were shorter than the floating and sinking tasks. Both were audio-video recorded to enable subsequent transcription and analysis. In addition to 'global' ethical consent, consent for the recording was obtained verbally from all of the children prior to participation.

Using the information gained from the unstructured observations it was clear that science tuition in all schools usually took place either at whole class or small group levels. This occurred regardless of the age of the children. The small group approach, which is often termed collaborative learning groups (Tunnard & Sharp, 2009) has been shown to be particularly effective for supporting children's learning in science (Driver, et al., 2000; Rivard & Straw, 2000). In light of this key finding the pilot studies were also structured to take place in small groups, the number of children in each group varied from 3 to 5. The researcher and the class teachers were responsible for grouping the children and in all cases attempts were made to ensure that the children working together were comfortable in each other's company.

In all instances participants were briefed as to the purpose of the activities, the use of the audio-video recordings, encouraged to work as a group as they normally would during a science practical, and informed that if they were unable to answer any of the questions or perform tasks it was perfectly okay to say 'I don't know' or 'I can't'. The studies were helpful for identifying practical issues such as the placement of cameras and the appropriateness of the materials used in the science activities for all of the age groups of children as well as offering an opportunity to develop questioning skills that could be used with all of the age groups. In the second instance the preliminary data driven approach to analysis permitted the early development of the analytical frameworks that would be used in the final study. Prior to undertaking the pilot studies two pre-screen instruments and two practical science activities were developed and planned.

The two pre-screen instruments were used to establish a baseline for the children's ideas at the beginning of the activities (see appendices a and b), one for electricity, and one for floating and sinking. These instruments were compiled using a range of teaching materials and by adapting a methodological approach used in the Primary SPACE projects that asked children to complete drawings and pre-formed sentences. The electricity pre-screen was developed by paying particular attention to the Primary SPACE Report on Electricity (Osborne, et al., 1991), in this project the researchers had asked children to complete a drawing of a bulb and battery in order to make the bulb light. In the current study, this approach was used but for the older

children the drawing contained the scientific symbols for battery and bulb rather than a picture of a battery and a bulb. In order to ensure that children were familiar with the symbols the researcher pre-screened children using a list of symbols, all groups that were able to identify these were given the pre-screen sheet containing symbols. This ensured that if children were not certain of the symbols they were given a sheet that would facilitate their understanding of the task. In addition to the drawing completion, children were asked to complete a pre-formed sentence “The bulb lights because...” with their own response. As this task demand was more difficult for the Year two children, the researcher collected their individual verbal responses to the pre-formed question on the video recordings and inserted these into each child’s sheet.

In the pre-screen to the floating and sinking activity children were asked to complete a drawing to show what they thought floating and sinking was by drawing in at least two objects one floating and one sinking. The design of the worksheet was guided by Bryant (1981). Children were then asked to complete two pre-formed sentences with their own ideas of why things float and sink, the sentences were structured similarly to those for the electricity activity. For example, “Things float because...”

Table 8 and Table 9 provide an overview of the design of each of the practical sessions. Each stage of investigation is mapped to the specific science concepts under investigation. The aims attached to these activities were as follows (see Tables 8 and 9 for further details):

- to elicit children’s ideas and concepts in relations to electricity, and floating and sinking;
- to explore the way in which children approach the problem solving tasks within each practical activity;
- to explore to what extent it is possible to instigate conceptual change or challenge through practical science activities;
- to provide children with the historical context to the discovery of the scientific principles that were being studied by discussing important science stories (Millar & Osborne, 1998)

- to explore to what extent a variety of responses to the tasks, verbal and non-verbal, reveal the nature of children's ideas and concepts in relation to electricity, and floating and sinking.

The physical spaces in which the research was undertaken was structured in order to promote collaboration between the children and the children were prompted to work with each other as well as with the researcher.

<b>Electricity</b>	
<b>Activity / Aim</b>	<b>Science Explanation</b>
Baseline probe of understanding of electricity	<p>Electricity is a term that describes a variety of phenomena resulting from the presence or flow of electric charge.</p> <p>Electric charge is a property of subatomic particles, which gives rise to and interacts with the electromagnetic force. Charge originates in the atom, in which the most familiar carriers are the electron and proton.</p> <p>Electricity is used for a variety of purposes but children may be more familiar with the use and effect of electricity in the home with electrical appliances such as televisions, cookers, kettles, gaming devices.</p>
Identification of symbols used for electrical components	A child who is able to identify the symbols will show that they have understood that these can be represented using shorthand methods.
Complete worksheet containing a diagram of a bulb and battery	Children who understand that electricity needs a path (a circuit) should complete the drawing to show wires connected to either side of the bulb (making contact with the metal base) and drawn back to connect with the battery.
Constructing circuits Probe of understanding of the simple circuit	<p>The bulb lights because the circuit provides a path through which the negatively charged electrons can 'flow'.</p> <p>The battery produces the charge (can be conceived of as 'force' or 'push' too) through a chemical reaction that occurs between the components within (the exact nature of this depends on the battery).</p>
Adding switches	<p>When the switch is off the circuit is incomplete and there is no path for the electric charge to flow through.</p> <p>When the switch is on it completes the circuit and the electric charge can flow freely around the circuit.</p>
Make a series circuit	<p>In a series circuit adding additional bulb increases the resistance in the circuit, this prevents the electricity from flowing as freely in the circuit and the bulbs appear dimmer equally so if the bulbs are identical. Provided the bulbs are matched they should both shine with the same intensity. Adding more batteries increases the electric charge (can be conceived of as 'force' or 'push' too) in the circuit this enable more energy to reach the bulbs and increases the intensity of the bulbs, they glow brighter.</p> <p>The removal of a bulb in a series circuit creates a gap in the circuit and the electric charge</p>

	is not able to flow.
Make a parallel circuit	The removal of a bulb in a parallel circuit only affects the branch on which the bulb sits, the bulbs in other branches on the circuit remain lit.
Measuring electricity	Electricity can be measured in amperes and volts. Amperes measure the electric current in the circuit, the current consists of the any moving charged particles. The measurement of current remains the same wherever it is measured in the circuit. The potential energy in a circuit is measured in volts (this should be the same as the batteries) and requires the measurement to be taken in parallel.
Problem Solving Activity: Testing materials for conductivity	Most metals conduct electricity although some do so better than others. Items conduct or insulate depending on their underlying molecular structure, this requires an understanding of materials.
Challenge ideas of how circuits work through a practical demonstration of the behaviour of the subatomic particles in electric charge using an analogy	Negatively charged electrons move around the circuit carrying energy to the bulb, the electron move from negative to positive poles of the battery.
Discussion of the story of Alessandro Volta	Volta was perhaps the first person to harness the power of electricity and this story will be used to add context to the children's understanding.
Final probe of electricity concepts	If the conceptual challenge aspect of the task was successful the children should respond to the final probe by using discussions of electron movement in their responses.

*Table 8: The science activities incorporated in the planning for the electricity tasks mapped against the target science explanations investigated.*



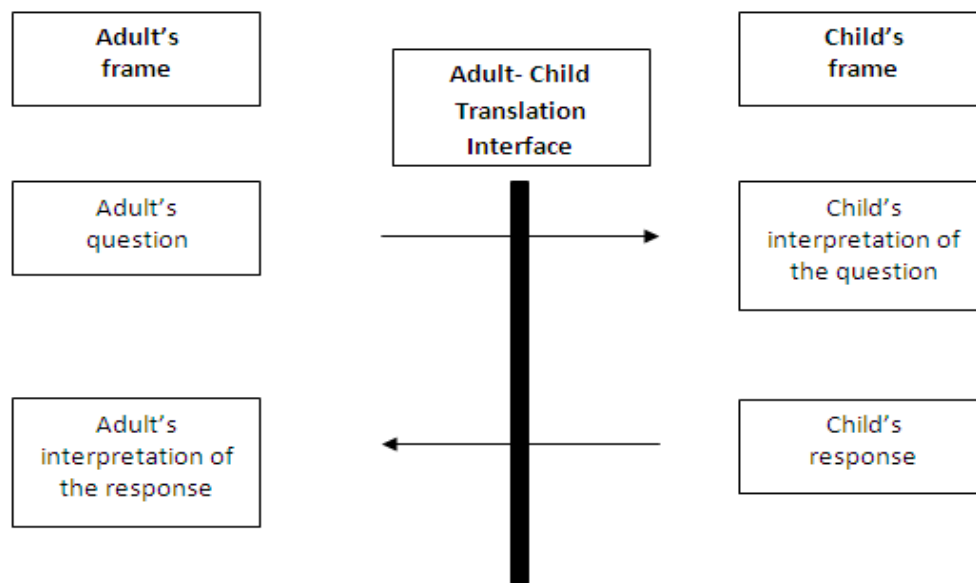
Floating and Sinking Activity	
Activity / Aim	Target Science Explanation
Baseline probe of students definitions for floating and sinking	When an object is submerged in any fluid it is considered to be floating if it tends to move upwards or if it stays at the surface of the water, if an object moves downwards it is considered to be sinking.
Guess what floats / sinks Investigate ordering / sequencing skills Ability to generate hypotheses Ability to set a fair test	Objects can be categorised according to their properties as to whether they will float or sink, dense objects tend to sink whilst objects with a low density float. Objects float when air is enclosed, the air lowers the density.
Test which items float and which sink	<p><b>Archimedes' principle:</b> A floating object will experience an upthrust force from water, equal to the weight of water displaced (pushed aside). It will sink into the water until it reaches the point where the weight of the water pushed aside equals its own weight. For an object that is floating, the mass of the material equals the mass of water that is displaced by the object (1 kg = 1 l of water). Dense objects cannot displace enough water to provide an upthrust force to counterbalance their weight, so they plummet below the surface. Objects made of material denser than water (e.g. a boat made of iron) can still float if they contain air so that the mean density is less than that of water. Objects float if the upthrust force from the water can balance their weight (gravity force).</p> <ul style="list-style-type: none"> <li>• Objects float depending on their density compared to water; for an object to float its density needs to be less than that of water.</li> <li>• Objects float when air is enclosed in an object; their density is lowered, thereby increasing the likelihood of floating.</li> <li>• The upthrust depends on the amount of water displaced.</li> <li>• Objects float better in salt water (density of salt water is greater than that of pure water).</li> <li>• Water surfaces have a cohesive force (surface tension) that makes them act like a 'skin'.</li> <li>• Small, dense objects (e.g. a pin; a water spider) can 'float' on the surface of water without breaking it, due to surface tension effects.</li> </ul>
Probe of student's understanding of why some things float and some things sink	
Probe of whether shape affects whether things float	
Test whether plasticine floats or sinks	
Problem solving activity:	Changing the shape of the plasticine changes the amount of water that it is able to

Moulding plasticine to make it float Add marbles to the plasticine in order to see how much weight it can hold before it sinks	displace, if the new shape is able to displace enough water it will float.  The marbles are additional weight but if these are placed in the plasticine so that they are balanced the object will still float (this is how boats work).
Probe of conceptions of why the plasticine floats once the shape is changed	
Adding weight to the plasticine models  Ask children to gently place marbles into their models	
Demonstration of water displacement through a balloon activity	By encouraging children to push the balloon (which floats) down into the water they are able to feel the upthrust force and see the water that is displaced by the object.
Discussion of the story of Archimedes	In order to help the children understand how the principles of water displacement was discovered the story of Archimedes discovery will be used to add context.
Discussion of density	The density of an substance influences whether or not it will float or sink.
Final probe of floating and sinking	If the conceptual challenge aspect of the task has been successful the children will discuss density and forces such as upthrust during the final probe.

*Table 9: The science activities incorporated in the floating and sinking task and the target science explanations that they investigate.*

## **4.7 Johnson and Gott's Adult-Child Translation Interface**

Having critiqued the different approaches to studying children's ideas that have been evident within the research and having subsequently developed an effective approach that aimed to capitalise on the use of a multiple-method which aims to reduce weaknesses, there was one final level of criticism that it was important to address in this thesis. In an influential paper investigating the validity and reliability of evidence investigating children's ideas in conventional terms Johnson and Gott (1996) presented the argument that the research of that time had operated under the illusion that the interpretation of children ideas was a straightforward process. Critically, Johnson and Gott (1996) proposed that research interpretations operating under this 'illusion' may be open to misinterpretation of children's actual abilities and that researchers were misguided because they failed to recognise that adults and children may hold disparate frames of reference. The frames of reference that individuals hold are influenced by their experience and knowledge, and as such, these frames of reference will influence the ways in which communication is interpreted and the ways in which subsequent responses are framed. Whenever an interaction takes place, these frames of reference will be active. Therefore, it is important to note that at least two frames of reference will operate at any one time. Thus, when adults, particularly researchers, are interviewing children in order to ascertain their knowledge they need to take account of the different frames of reference that will be in operation: theirs and that of the child. It was suggested that any interaction between an adult and child will cross the boundaries of these frames of reference on more than one occasion. Figure 14 demonstrates the crossing points between the frames of reference that occur during a one question event, during this short interaction on two occasions information passes through a translation interface. According to Johnson and Gott this adult-child translation interface is the point at which the understandings of the two frames of reference converge. It is also the point at which intended meaning can be lost or misinterpreted. As Figure 14 indicates the frames of reference may influence the ways in which questions are interpreted, subsequent responses are generated, and the final interpretation of meaning that is ascribed to the response.



*Figure 14: The adult-child translation interface adapted from Johnson & Gott (1996).*

In their research Johnson and Gott (1996) suggested that translation differences can easily arise if children do not interpret questions according the frame of the adult or if the adult interprets a child's response using an underlying meaning that significantly differs from that intended by the child. One such example of misinterpretation occurring in the adult-child translation interface was presented in a study by Leddon, et al. (2008). Leddon, et al. (2008) suggested that the meanings of words is often taken for granted and the complacent view that alignment between words and the underlying concepts are one and the same may lead to a misunderstanding of children's abilities. In their two reported studies investigating the appreciation of the concept linking living things in American children across three age groups, 5, 6, and 9 years, it was revealed that by changing the language used from 'alive' to 'living thing' younger children were more able to demonstrate an appreciation of this scientific concept. In the first study conducted with 44 participants children were asked to categorise 17 laminated cards depicting photographs of objects (for example, a bear, a tree and the sun) according to whether they were 'alive' or not. The results to this study demonstrated that even the older children who had received tuition in scientific concepts such as cell biology including plant cells were less able to attribute the status of plants to the category 'alive'. In a second study conducted

with 90 children who completed the same categorisation task but this time using the concept term 'living thing' it was revealed that even the youngest participants were able to distinguish plants from non-living objects. The results to this study were interpreted as demonstrating how basic terms can be misinterpreted by children to suggest animacy, a characteristic that is not readily observable in plants. The discussion presented by Leddon, et al. (2008) implied that the use of ambiguous terms can mask young children's appreciation of scientific concepts due to a misalignment between the concept terms accepted by adults and children's meanings ascribed to them. In addition it was suggested that

*"it is important to characterise not only the scientific concepts children bring to the classroom, but how children encode these concepts in words". (p. 467)*

This study therefore accepts Johnson and Gott's (1996) view that misunderstandings that occur within the adult-child interpretation interface could produce misleading results regarding children's understanding of scientific concepts and all findings are considered in these terms. As such, this research and as proposed by Johnson and Gott (1996), care was taken to remove ambiguities in meaning in order to facilitate children's accurate interpretation adult questions and subsequent validity and reliability in the interpretation of research findings.

In order to overcome this issue Johnson and Gott (1996) recommend that researchers need to find the neutral ground for interpretation. Bearing these issues in mind the researcher was extremely careful with the terms that were used throughout the activities and where possible aimed to use the same terms as the children in order to reduce misunderstanding. In addition, attention was paid to the gestures that children produced as these could, at times, reveal insight into the children's ideas that were not present in their verbal speech.

## **4.8 Discussion**

In this chapter, general methodological considerations of the research project were presented and discussed. At the beginning of the chapter, philosophical issues were

debated and it was concluded that in order to facilitate the effectiveness of the research discussed here a pragmatic approach was the most appropriate. This chapter then discussed the design of the research undertaken for this thesis, introduced the participants, and provided background information regarding the demographic details of the schools who participated. The discussions then reviewed some of the traditional constructivist approaches to exploring children's ideas and debated these in the context of research findings. A multiple-method approach utilising group interviews, participant observation and practical science activities was developed. The activities were structured around dialogic teaching principles and collaborative learning groups in order to provide opportunities for the participants to develop their ideas using the materials given. The multimodal, task-based approach was then developed and piloted in three schools, the results of which were further used to develop materials for Research Phase 2 (a full evaluation of the results of the pilot studies is presented in Chapter 5).

Importantly, one issue arising from Research Phase 1 was that in order to facilitate effective data analysis it would be advantageous to utilise the NVivo software programme. This programme was specifically designed for use with qualitative data and enables researchers to code a range of materials according to pre-selected themes or topics. As it was anticipated that the research undertaken in Research Phase 2 would generate a large quantity and breadth of data, the NVivo software would offer one solution to the difficulties of data tracking. As effective Nvivo projects can take some time to develop, coding strategies using a bottom-up process were also piloted and used as a basis for the subsequent coding (see also Chapter 5). Issues related to managing data were just one of the findings resulting from the pilot studies. Another key finding was the need to adjust the structure of the electricity activities so that it included an element of conceptual challenge, thus making it fully comparative with the floating and sinking activities. Using ideas from the science teachers in the schools themselves it was decided that an additional activity which used smarties in order to model and act out the role of electrons in a circuit should be added. The importance of the dialogic teaching approach (Alexander, 2004) was also acknowledged and the research sessions were adjusted accordingly. Finally, the importance of the multi-modal aspects of the task was highlighted (these will also be discussed in more detail in Chapter 5) in order to show how the multimodal, task-

based approach was developed and how multimodal forms of analysis were generated using the traditional constructivist framework as an foundation. In the next chapter, a more detailed discussion of the multimodal research will be presented. The results from pilot studies will be used to highlight the importance of this approach and consideration will be given to the development of the analytical framework and the techniques developed in order to support the data analysis used during this study.

## **Chapter 5 Methodology 2: The Development of a Multimodal, Task-based Approach**

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### **5.1 Introduction**

This chapter focuses on the major original contribution that this work makes towards the development of a multimodal, task-based approach as a means of studying children's ideas in science. This approach aimed to utilise interviews about instances, focus groups and observation. As detailed in Chapter 4 and further discussed in this chapter, the approach also adopted a dialogic teaching technique and collaborative learning groups. This approach was developed to study the use of various modes of representation used in combination by learners undertaking practical activities in the science classroom. This chapter also outlines the original approach taken to data analysis.

In this chapter a full review of the importance of attending to children's gestures and other non-verbal behaviours is discussed and evaluated using the findings of key research into multimodal aspects of learning in general. The results of the recent pilot studies conducted as a part of Research Phase 1 (see Chapter 4 for details) are also used in order to demonstrate how the multi-modal task based approach to studying children's ideas in science was developed for application in Research Phase 2. This chapter then turns to a full discussion of the development of an appropriate analytical framework in order to capture children's gestures and evaluates their importance in relation to what they reveal about children's ideas and knowledge. This chapter presents and discusses the storyboarding technique that was developed as a part of Research Phase 3 and used in order to analyse the practical science activities in a more holistic manner than usual. Finally, details of a timeline analysis framework developed in order to permit the detailed analysis of the development of children's ideas within the session over time are presented. It is



important to note here that this analytical approach aimed to build in the traditional techniques for studying children's ideas (detailed in Chapter 4).

## **5.2 The Importance of Attending to Gesture and Other Non-Verbal Behaviour**

As noted in previous chapters the majority of research investigating children's ideas in science relies to some extent on the interpretation of children's verbal reports made during either interviews or completion of various scientific tasks. One key methodological difficulty with these studies is that it is hard to be certain that what children tell us that they know is actually the same as or a full account of what they do know. However, recent research suggests that non-verbal behaviour such as gesture may offer an alternative or complimentary route to understanding children's knowledge. Gestures are considered to emerge in young children before they are able to talk (Bates, 1976; Thompson & Massaro, 1994) and remain present across cultures and languages in to adulthood (Wundt, 1921; Mead, 1934; Feyereisen & de Lannoy, 1991; Kendon, 1997). When adults talk they often produce gestures even when the listener cannot see their non-verbal communication and it has been proposed that gestures are deeply integrated with other intellectual abilities (Roth & Lawless, 2002) including competence in navigation and orientation, sense of direction, and language (Haviland, 1993; Levinson, 1997; Widlock, 1997). Research has suggested similar behaviour occurs in children, with children frequently spontaneously producing gestures when they are talking (Kelly, et al., 2008).

### **5.2.1 What is a Gesture?**

As defined by Goldin-Meadow (2003a), gesture is a term that encompasses a wide range of behaviours. For the purposes of this work the focus is on the movements that children use when they are discussing their science ideas. Previous work, has however, defined the different forms that gestures or gesticulations can take (Kendon, 1980). For example, McNeill (2005) proposed that gestures can take four possible forms and each of these has its own relationship to speech, carries specific linguistic properties and conventions, and levels of semiosis (which is defined as

meaning). These four forms are: gesticulations, pantomimes, emblems and sign language (detailed in Figure 15). Whilst all four of McNeill's forms of visual communication are widely used in research, this work is on gesticulations as these are not conventionalised and can carry meaning that is not conveyed in speech.

Form of gesture	Gesticulations	→ Pantomime	→ Emblems	→ Sign Language
Relationship to speech	Obligatory presence of speech	Obligatory absence of speech	Optional presence of speech	The same
Linguistic properties	Linguistic properties absent	The same	Some linguistic properties present	Linguistic properties present
Conventions	Not conventionalised	The same	Partly conventionalised	Fully conventionalised
Semiosis	Global and synthetic	Global and analytic	Segmented and synthetic	Segmented and analytic

Figure 15: Kendon's continuum of different types of gestures proposed by McNeill (1992, 2005).

Gestures can occur in isolation or they can, and more typically, accompany speech. Goldin-Meadow (2003a) proposed that gestures which accompany speech take on the intentionality that is found in verbal language, thus it is proposed that they are used to communicate something. McNeill (2005) proposed that gestures are an important aspect of communication and that they are linked to both speaking and thinking so much so that the imagery formed in gesture is part of an inseparable system in the brain. In a seminal book, *"Hand and Mind"*, McNeill (1992) highlighted that gesticulations or gestures can take four forms:

- iconic gestures – which display a close link between the gesture and the speech, this form of gesture can refer to the object or action being mentioned in the verbal articulation and appears as though connected;
- metaphoric gestures – similar to iconic gestures but the content is abstract;
- deictic gestures – gesture which are used to indicate people, objects or locations in the real world;

- beat gestures – movement that appear to beat out musical time and have the same form regardless of the verbal articulation.

It was later proposed that these gestures are produced unconsciously and that they appear in everyday speech (Beattie, 2004). Goldin-Meadow (2003a) also proposed that iconic, metaphoric and deictic gestures have the potential to reveal the speaker's thoughts and in some cases may actually help to shape these thoughts.

Although the interpretation of gestures can be open to subjective bias on the part of the researcher the study of children's non-verbal behaviour may provide an alternative route to language that enables the researcher to gain insight into their thoughts (Kendon, 1980; McNeill, 1985, 1987, 1992). McNeill (1987, 1992) suggested that the gestures that are produced when people speak are a secondary means of conveying meaning. As such, gestures do not stand alone but are part of an integrated communication system, both language and gesture working together to provide insight into the mental processes and representations held in the mind of the communicator. However, McNeill also proposed that gesture communication differs from speech as it is controlled by different constraints. Because of this gesture may reveal a different kind of knowledge when compared to speech. Indeed Goldin-Meadow, et al. (1992) have proposed that the gestures that children produce when undertaking problem-solving activities, for example Piagetian conservation tasks, may reveal more tacit or developing knowledge than hitherto acknowledged. It is worth noting here that this distinction between tacit knowledge and explicit knowledge in available verbal report bears striking resemblance to the distinction made by Donaldson (1992) between 'light' and 'dark'. In her synthesis on "*Human Minds*", Donaldson proposed that children's knowledge may exist on a metaphoric continuum that ranges from 'light' to 'dark'. Children are consciously aware of 'light' knowledge and as such, it is readily available for verbal report. In contrast, other bits of knowledge are contained within the 'shadows' or indeed in 'darkness', with this knowledge sitting either on the borders of conscious awareness or unavailable for conscious processing. As such this knowledge is rarely reported verbally but can be observed in behaviour. Donaldson stated: "*paradoxically, we can know without knowing that we know*" (p. 21). This view is supported by a study investigating mathematical algorithms and their use by 58 children in both their speech and

gesture (Alibali & Goldin-Meadows, 1993). The results of this study demonstrated that children had some procedures that were evident only in one modality (e.g. only in speech or gesture) and that across the children as a whole the number of procedures found only in gesture were higher than the number found only in speech. Thus, it was suggested that when gesture is analysed along with speech, clues and cues to developing knowledge states may be provided (Goldin-Meadows, et al., 1992). This view has also been empirically supported in studies investigating children's learning in science (Siegler, 1976; Crowder & Newman, 1993; Newman, 1996; Roth & Lawless, 2002).

### **5.2.2 Gesture and Learning Science**

Early research investigating 5 and 8 year-old children's learning on an activity balancing weights (Siegler, 1976) revealed that the 8 year-olds gave non-verbal indications of their readiness to learn whilst the 5-year-olds did not. Siegler's work which spanned 3 experiments and included a total of 120 female children drawn from a private school in America, not all of whom participated in the different conditions, aimed to unpick the developmental difference in children's thinking. It was suggested that non-verbal indicators such as head movements could be interpreted as revealing the older children's consideration of distance as a factor in the balance scale problem even though in their verbal discussions they did not reveal this consideration. The subsequent results of the study that investigated the potential benefits of tuition at different stages of concept development indicated that only the eight-year-old children benefited from instruction. As well as demonstrating readiness to learn, other research has suggested that gestures may be used to complete or complement children's explanations and their scientific understanding. Crowder and Newman (1993), for example, studied the speech and gestures of 6th grade American children from two schools as they learned about seasonal change. The gestures and speech of 13 children during science lessons were used in the final analysis in which Crowder and Newman (1993) outlined a five-point distinction on the different types of gestures involved:

- speech-dependent / referential gestures (iconics and metaphors) and discourse gestures (beats);
- word-like or pantomimed gestures which may substitute for words within verbal syntax;
- points to a model;
- gestures made with the whole body;
- meaningful manipulation of a physical model.

The analyses of videotapes revealed that children used these different types of gestures in three ways. Some gestures were redundant to the speech content; others served to enhance the ideas expressed through speech; and finally, in some cases, gestures served as carriers of scientific meaning. It is worth noting that Crowder also suggested that the use of gestures by children may support their construction of new conceptual understanding and this view is also supported in the work of Goldin-Meadow (2000). This led Crowder to conclude that “*as long as ideas outstrip scientific vocabulary, one can expect to see gestures used by elementary science students to carry unstated ideas*” (1996: p.176). Goldin-Meadow, perhaps one of the most prolific writers investigating children’s gestures, agrees that gestures do indeed convey knowledge and understanding and discusses ways in which gestures may be used in an educational context to support teachers’ (Goldin-Meadow, et al., 1992; Goldin-Meadow, 2000). Goldin-Meadow’s work covers a vast range of subjects from investigations exploring the use of gestures within communication by congenitally blind children (Iverson & Goldin-Meadow, 1998) to the ways in which gesture paves the way for language development (Iverson & Goldin-Meadows, 2005). In a review that draws on a body of research investigating different areas of children’s problem solving ability, Goldin-Meadow, et al. (1993) suggested that stability between speech and gesture characterises a stable understanding of a concept, while mismatch between the two elements characterises the time in which children are moving between conceptual understandings. It is argued that the “*gesture-speech mismatch signals to the social world that an individual is in a transitional knowledge state*” (Goldin-Meadow, et al., 1993: p. 279). Goldin-Meadows, et al. (1993) suggested that this signal may be a behavioural feature of the child’s ability to benefit from tuition within Vygotsky’s Zone of Proximal

Development (Vygotsky, 1978). Whilst the proposal that mismatches indicate a 'readiness' to learn through the Zone of Proximal Development has yet to be fully supported, other aspects of Goldin-Meadows' proposal do appear to indicate the existence of more than one conceptual framework existing in the children's responses at the same time. According to the analysis offered new concepts and conceptual understandings appear in gesture first before subsequently being subject to speech-based reports. Roth and Lawless (2002) upheld this view when they stated:

*"In terms of conceptual development, gestures express features of scientific concepts and relations prior to the equivalent representation in verbal discourse...gestures appear to scaffold the emergence of students' observational and theoretical language...." (p. 287)*

Roth and Lawless' research investigating the role of gesture in the development of abstract scientific concepts in American children of different ages (grades 4 - 12) draws evidence from ten years of classroom studies. The authors reviewed videotapes from different science subjects including simple machines, ecology, physics, chaos theory, and static electricity, and concluded that when students learn science they first demonstrate their knowledge through metaphoric gestures while the appropriate scientific language emerges much later. One example presented is of 10<sup>th</sup> grade children in a German physics class who were learning the scientific concepts associated with static electricity through investigations that they had designed themselves. This analysis demonstrated how one student, Paul, completed his sentences with physical movements that demonstrated different aspects of scientific understanding not present in his verbal articulation of his ideas (see Figure 16).

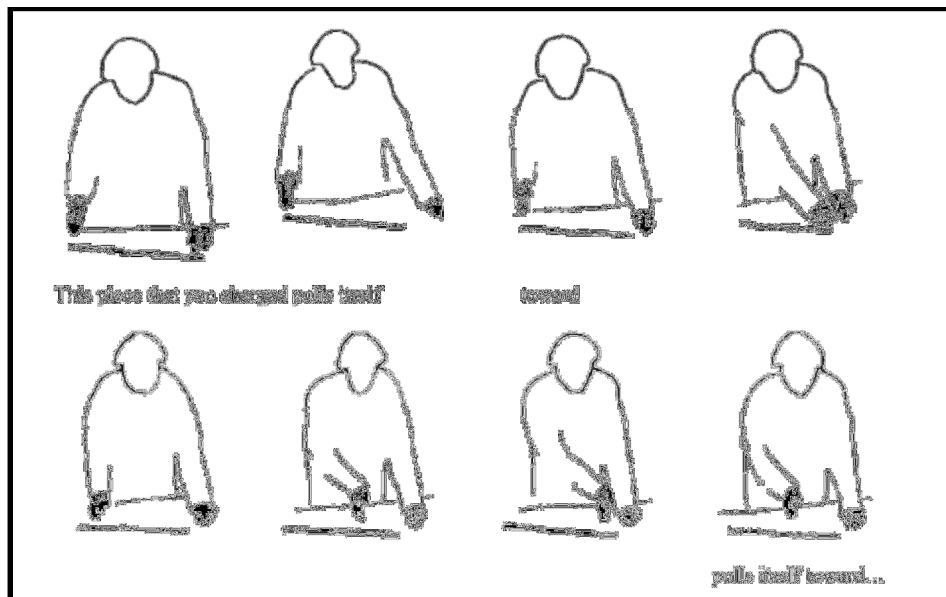


Figure 16: A 10<sup>th</sup> grade German student uses his gestures to depict electrons and their movement in a metal rod in order to explain why a pith ball bounced in the experiment he had conducted (Roth & Lawless, 2002).

Using these and other findings from the study, Roth and Lawless concluded, “*our data seem to suggest that students already have a semantic model, but their verbal competencies have not yet developed.*” The lag between the formation of a semantic model and establishing appropriate verbal competencies may have a significant impact on younger children’s verbal reports especially when younger children may still be developing general language competencies. In addition to providing the learner with a scaffold that facilitates the development of appropriate linguistic labels, a multimodal study investigating the use of gesture in a group of three American 6th grade children proposed that gestures were used to socially negotiate scientific understanding of plate tectonics (Singer, et al., 2008). Singer, et al.’s (2008) study systematically explored the small group interaction of the 3 students as they developed their conceptual understanding of the plate motions. The data were drawn from 40 video-recorded episodes of classroom activity and analysed for both speech content and non-verbal behaviour. The resulting analyses revealed that students were able to “*change both their own and one another’s understanding by manipulating embodied representations of the domain concepts being explored*”

(p.383). In addition, the study revealed that the gestures children used for concepts preceded verbal articulation of concepts for every student investigated.

With the evidence reviewed in mind, and the significant finding that a mismatch between gesture and speech may indicate knowledge in transition, is of fundamental importance to this study and its investigation of notions of conceptual change. As Goldin-Meadows, et al. (1993) stated:

*“In gesture-speech mismatch, two beliefs are simultaneously expressed on the same problem – one in gesture and another in speech. We suggest that it is the simultaneous activation of multiple beliefs that characterises the transitional knowledge state and creates gesture-speech mismatch.”* (p. 279)

If indeed this proposal does indicate that conceptual restructuring is taking place a detailed analysis of children’s speech and gesture during science activities may be helpful for highlighting the processes of conceptual change.

Critically, the interpretation of gestures can be open to subjective bias, for example, one person’s interpretation of the content of a gesture may differ to another’s (as shown in Johnson & Gott’s translation interface, Chapter 4, Section 4.7). However, despite this potential problem, the study of children’s non-verbal behaviour may provide an alternative route to language that enables the researcher to gain insight into their thoughts (Kendon, 1980; McNeill, 1985, 1987, 1992). McNeill (1987, 1992) suggested that the gestures that are produced when people speak are a secondary means of conveying meaning. However, McNeill also proposed that gesture communication differs from speech as it is controlled by different constraints and because of this gesture may reveal a different kind of knowledge when compared to speech. However, McNeill’s proposal is not without its criticisms and Krauss (1998) proposed that in fact gesture and speech may be two separate systems, with gesture merely playing a supporting role for accessing words during speech. Whilst such criticisms have been highlighted in the literature, the importance of studying gesture for both research and applied work has been strongly supported (Kelly, et al., 2008). This proposal and others like it have led to the development of multimodal research as a field.



### **5.2.3 Multimodality: a Richer Context for Understanding Children's Ideas**

From what can be established, multimodal research is still in its infancy but is beginning to gain momentum in science education research (Ogborn, et al., 1996; Kress, et al., 1998; Kress, et al., 2001). The indication that communication takes place through a number of modes including language and non-verbal behaviours such as gesture forms the foundation of this approach (Kress, et al., 1991; Jewitt, et al., 2001; Jewitt, 2011). An analysis of multimodal data has the potential to interpret different modes of communication for their underlying meaning. Studies which have adopted this approach in order to explore how scientific concepts are constructed in classroom environments already exist (Jewitt, et al., 2001; Franks & Jewitt, 2001; Roth & Lawless, 2002; Jaipal, 2009). The use of multimodal analysis in science education is a developing area but the one study by Jewitt, et al. (2001) explored learning in the science classroom using this approach. The authors proposed that by extending communication to cover all modes the study was able to reveal the “*central role of action in the learning of science*” (p. 5). Jewitt, et al. (2001) suggest that texts are one form of evidence that can reveal students' knowledge, whilst other forms such as verbal language represent other modes of understanding. The analysis presented by Jewitt, et al. is based on observations of pupils producing texts, interviews with pupils about their experiences and an analysis of the texts themselves. In their conclusion the authors suggested that in the process of constructing an understanding of a scientific concept children collate, select and transform information from the whole range of communication modes. In addition the authors proposed that by adopting a multimodal perspective advantages are gained over approaches which rely on verbal responses alone. In a further paper, Franks and Jewitt (2001) suggest that speech and gesture have different but complimentary roles in children's conceptual thought. Each mode has a relationship to the way in which meaning is made. Using excerpts from a science lesson transcript the authors demonstrated how children revealed conceptual knowledge through non-verbal communication such as body posture, facial expressions, and gestures. In order to complete their analyses the authors viewed the video tape of

the science lesson on many occasions, sometimes with only sound, other times with only image and finally with both sound and image together. This approach enabled the researchers to tune into all aspects of communication as expressed through the variety of modes. The results of the study demonstrated that action (for example, body posture, gestures and orientation to other students) serves the role of communicating meaning as well as shaping the subsequent interaction. Jaipal (2009) presented one final study of interest to the current research project. Jaipal investigated how a science teacher used different modalities when teaching biology to children. Jaipal constructed a transcription approach that categorised modalities according to the order in which the teacher employed them when explaining a number of target concepts. The results of this study demonstrated that the teacher selected different modalities in order to express different levels of conceptual understanding. Jaipal proposed that these results demonstrated the way in which different communication modalities can be used to scaffold the development of scientific concepts.

In addition, the results of the pilot studies for Research Phase 1 of this thesis, Chapter 4, provides additional evidence that such multimodal analyses do indeed add greater depth to our understanding. By way of example, here, it is clear that the children taking part in the electricity activity use non-verbal cues to complete their intended meaning (*RS = researcher, other non-verbal column is used to highlight aspects of social interaction and non-verbal behaviour that is not gesture based*).

Time	Person	Verbal Report	Gesture	Other non-verbal
07:22	RS	Ok, so can you tell me what is happening to make the bulb light?	Points to the completed circuit.	
07:31	Rachel			Laughs and lifts her hand to her hair.
	Rachel	Erm, the batteries are making the power go all the way, no, the electricity go all the way to make the bulb which is making it... (hesitates at this point).	Uses her right index finger to trace a path which begins by touching the battery pack and then follows one of the wires from its connection at the bulb pack to the bulb.	
07:41	Sally	Light up.		Is watching Rachel's demonstration and looks at her as she hesitates. Following her articulation both girls look at each other, Sally has her hand across her mouth and Rachel smiles.
	Rachel	Yeah.		Giggles.
07:44	RS	Ok, do you agree with that?		Looks to other members of the group. Sam shakes his head and moves forward to speak.
	Sam	Is it cuz, like, on there, there's two pieces of metal like and on there and then if you like clip them on they'll...thing...like	Points to the metal connectors at the battery pack and then	

		something will go through there and it connects like on the metal to there which the battery power will go through there.	moves his hands to the connectors at the bulb, traces a path along the wire from the battery pack to the bulb using his right index finger, repeats this action by moving his hands back to the crocodile clips and then traces a path again along the wire to the bulb.	
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*Table 10: An excerpt from a transcript of Year 6 children taking part in one of the electricity activities developed for the pilot studies for this thesis.*

This excerpt can be compared with the conventional approach detailed in Chapter 4, page 114, such direct comparison reveals the additional dimension that is provided by using a multimodal transcript. Analyses of the data presented in the transcript demonstrated that whilst directional comments remain absent from the verbal reports offered by children when discussing their conceptions of electricity, such information is available in their non-verbal behaviour. With this evidence in mind it is suggested that although research interviews, focus groups, drawings and observation are useful for eliciting children's ideas it was anticipated that the research would require additional research protocols in order to analyse the potential interaction between gesture and other non-verbal behaviour and other responses. In light of this, an analytical framework was developed to accommodate this.

### 5.3 Children's Gestures in Science - Results of the Pilot Studies

The results of the pilot studies were subjected to a preliminary analysis in order to explore whether or not children used gestures during the activities, whether these appeared to be meaningful and whether or not this form of analysis could be used to inform on how ideas changed both within age groups and between them. In order to achieve this, the audio-visual recordings were transcribed for their content (Kracaucer, 1953; Schreier, 2012; Krippendorff, 2013) and coded using a bottom-up process in which emerging themes were identified and then explored. The most successful approach to capturing action and gesture was to use two static cameras in the classroom. These were located so as to give the best view of the children (Goldman, et al., 2007). A data-driven content analysis was then conducted in order to explore what types of gestures children used during the activities and what role these gestures appear to have within the context of the activities (Figure 17).

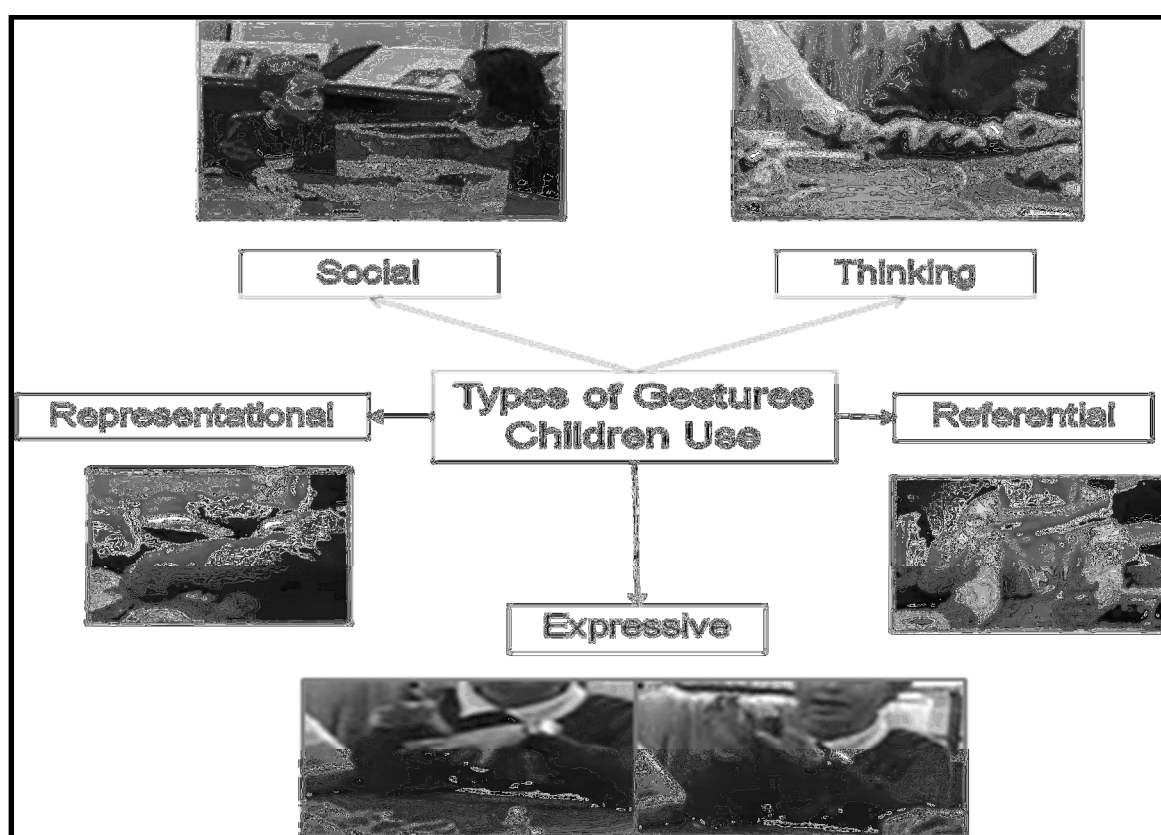


Figure 17: The different types of gesture identified during the pilot studies conducted as a part of Research Phase 1.

Overall the gestures appeared to fall into two categories: scientific and social (Callinan & Sharp, 2011). The scientific gestures came in four main forms:

- referential – e.g. pointing to objects, pictures or people in the immediate environment;
- representational – e.g. re-enacting the behaviour of objects, the content of pictures, or factors related to people;
- expressive – e.g. often including repetitive movements or building on representational gestures revealing the values associated objects, pictures or people;
- thinking – e.g. finger drumming, waving hands, head holding or face and hair stroking.

The children frequently used referential gestures during their discussions. These included pointing to objects, pictures or people, and appeared to be used in order to complete their discussions. For example, Alan, a Year 2 (7-year-old) boy; engaged in constructing a simple circuit, used a referential gesture to indicate the presence of an object that was not readily observable as he discussed why a bulb in the circuit lights up. His pointing gesture which was directed at the bulb in a simple circuit was accompanied with *“is it because there’s a little metal thing in there...”* The use of this gesture appeared to indicate his awareness of the functional role that objects such as the bulb’s filament, which is barely observable, play within electrical circuits.

Whilst referential gestures appeared to enable children to directly link their discussions to items within the science classroom, there was also evidence that rather than indicating objects directly, children would act out the behaviour of objects using their hands. These gestures were classified as ‘representational’ which appeared as ‘charades’ (e.g. the hands were used to represent an object, an event or the interaction between things). One Year 2 child, Mary, frequently used representational gestures as she worked through her ideas of floating and sinking: one hand was used to represent an object and the other for the liquid, in this case water, in which the object was floating. Her hands were positioned one above the

other, both palms facing downwards, the lower hand, which represented the water, remained stationary, whilst the top hand was gently lowered towards the stationary hand before being brought to a stop on top of the lower hand. This representational gesture appeared to be her way of explaining that the water remains stationary whilst the object is lowered into it, and once in place, the object is supported by the water and remained above the surface. Expressive gestures, which included repeated movements or emphasis, were used by children to demonstrate values such as the strength of responses. In one example, Joe, a Year 6 (11-year-old) child, cupped his hands and then repeatedly moved them apart through a sideways motion to indicate how he thought a bulb would brighten if more batteries were added to a circuit. Thinking gestures appeared to include behaviours such as finger drumming, head holding and face and hair stroking. In one example drawn from the pilot studies, the same boy, Joe, was discussing his ideas about electricity. As he did this he repeatedly paused and drummed his fingers on the table. This type of behaviour, which can often be seen as a disruption to group or class work, was interpreted as Joe's non-verbal method of signifying that he was thinking through his own ideas before making a considered response.

While scientific gestures appeared to play a crucial role in children's communication and in facilitating an understanding of children's scientific ideas, social gestures also appeared to have an important role for facilitating an understanding of how young children used input from peers in order to structure their responses to probes or to seek social support when they were experiencing uncertainty or difficulty in generating a response. During the course of the pilot studies there were many instances which demonstrated how the children used such non-verbal approaches to elicit help from each other. Whilst these gestures can be interpreted as demonstrating little regarding children's scientific ideas they appeared to be specifically useful for revealing how children negotiate meaning in groups. These findings can be related to the social aspects of constructivism as identified in Chapter 2, and more specifically can be located in the work of Solomon (1987) and the social aspects of constructivism identified by Driver (1995, see Chapter 3).

The preliminary analyses exploring the congruency between verbal and gesture-based communication further revealed that gestures did appear to contain valuable

information regarding ideas and concepts that are not included in verbal responses. For example, analyses of gestures produced during the floating and sinking pilot studies revealed that children might be considering variables such as the shape of objects even though such verbal references to shape were frequently omitted. Overall, it is proposed that this classification of types of gestures for the first time captures those that may be most relevant to the science classroom whilst previous studies and categories have been less domain specific in nature.

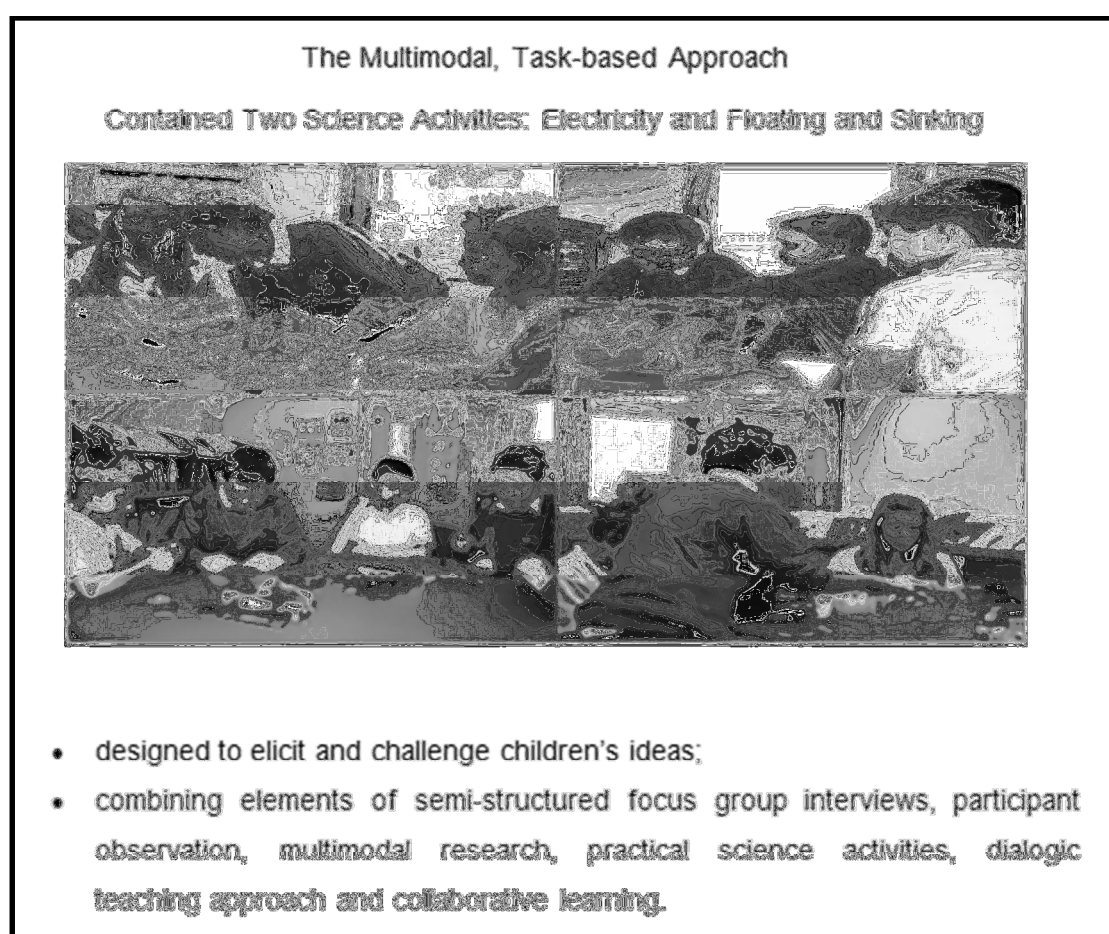
In addition to demonstrating the importance of children's gestures, the pilot studies were also used to further develop the methods used as detailed in Chapter 4. In addition the pilot studies informed the design of an analytical framework for analysing the data drawn from Research Phase 2's probes of children's ideas for electricity and floating and sinking.



## 5.4 Towards a Multimodal Analytical Framework

As discussed in Chapter 4, children were recruited to take part in two practical science activities. These activities were undertaken using the newly developed multimodal, task-based approach (summarised in Figure 18).

This method was developed from the review of the different approaches to data collection. This made it clear that for the aims of the current study no single approach offered the flexibility that was desired in order to explore children's ideas in adequate depth. In order to develop an appropriate approach different elements were drawn from the different methodological approaches reviewed.



*Figure 18: An overview of the multimodal task-based approach.*

The multimodal, task-based approach developed here (not to be confused with multiple methods or mixed methods) aims to achieve this by incorporating different methodologies into one design and it is anticipated that the strengths of each approach can be utilised to elicit children's ideas, by probing knowledge and understanding at an appropriate level of depth so that a richer insight of how they learn science can be achieved. This approach utilises interviews about instances and events (White & Gunstone, 1992), focus groups (Kitzinger, 1994), and participant observation techniques (Wragg, 1999) into a multimodal framework (Kress, et al., 2001; Taylor, 2006; Jewitt, 2011). It is proposed that by incorporating elements of these different methods into one framework the inherent difficulties with each of these research approaches can be minimised. This route to investigation provides a form of methodological triangulation (Denzin, 1978) but also offers a more holistic approach to investigating children's ideas. The approach is designed to reinstate the context of the science classroom by utilising collaborative group work (Howe, et al., 2007), a dialogic teaching approach (Alexander, 2004) and practical science activities that frequently form the basis of science education in schools. The guidance of the semi-structured interview schedule and structured activities permit both the elicitation of children's ideas and the opportunity to challenge these ideas through practical demonstrations of alternative explanations of the phenomena associated with electricity and floating and sinking. It is proposed that by challenging children's existing ideas, the subsequent multimodal analysis which aims to highlight areas of match and mismatch (Godin-Meadow, et al., 1992) between response types may begin to uncover the processes of conceptual change or at least the impact that conflicting information may have on existing knowledge. In addition, the incorporation of the observational approach permits the researcher the reflexivity required to adjust the interview schedule to suit the abilities of the participants as well as the opportunity to follow unanticipated events arising during the science activities.

In order to support the analysis of the multimodal aspects of the science activities it was clear that it was necessary to develop a new analytical framework in order to capture the levels of detail required. In the next section the development of this analytical framework will be described. This framework utilised content and multimodal analysis and a storyboard analysis which shows the underlying meaning

or content associated with each mode of communication (drawings, written and verbal language and gesture). Further to this in order to explore how ideas had changed, if at all, over time during the course of each science activity a timeline analysis approach was developed from the work of Givry and Tiberghien (2012).

### 5.4.1 Levels of Analysis and Comparison within the Study

As previously discussed, in order to capture the range of response types and explore them for their utility in supporting our understanding of children's ideas the analysis of data collected during the pilot indicated a number of levels was required. In addition, in order to explore how changes take place over time and how these changes may be influenced by the science topic studied or the age of the participants, the study would also be conducted with a multi-layered comparison of the data (see Figure 19 for a summary).

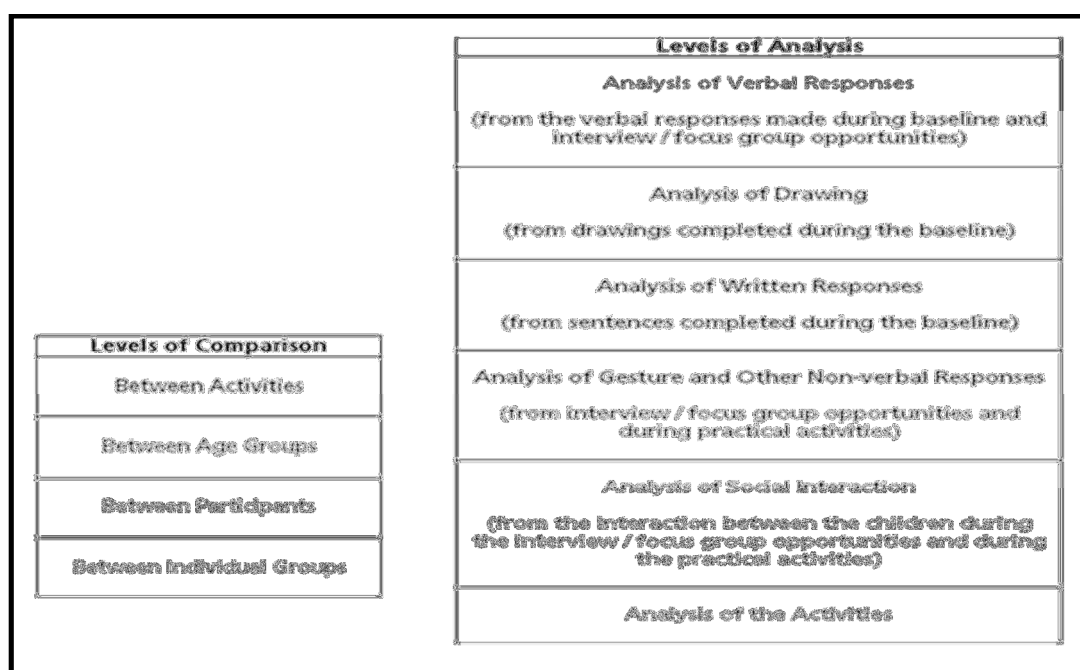


Figure 19: Levels of comparison and levels of analysis for Research Phase 3.

Notably in this study, it was important to attend to the content of ideas presented in verbal and written forms of language, as well as the content of drawing and the content of gestures. Although a review of literature revealed a range of different

analytical approaches that could have been taken (e.g. conversation analysis, and discourse analysis Goodwin & Heritage 1990, 1999 and Gee, 1999) it was determined that the most useful approach would be to use content analysis for attending to each of these levels (Krippendorff, 2012).

### **5.4.2 Content Analysis**

In order to explore children's ideas it was determined necessary to analyse the data in order to explore the underlying frameworks of understanding that the children were applying during the activity using content analysis. The roots of content analysis can be traced back to the beginning of the use of symbols and verbal discussions (Krippendorff, 2012). Despite these distant roots, contemporary content analysis has three features that Krippendorff (2012) proposed distinguish it from earlier forms:

- it is empirically grounded;
- it transcends notions of symbols, contents and intents;
- contemporary content analysis has been forced to develop a methodology of its own.

In summary, content analysis entails a systematic approach to reading text, images, and all other symbolic matter which is generated during research. It is defined by Krippendorff as:

*“...a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use.” (2012, p.24)*

Over the course of its history, content analysis has been used to address a range of topics including newspaper content, propaganda, computer text and social and political problems (Krippendorff, 2012). The analysis itself can come in two forms, a quantitative version which focuses on counts and occurrences of themes drawn from the data and a qualitative version where the process is used as a method for describing the meaning of qualitative data (Schreier, 2012). However, this distinction

of forms is not without its challenges and Krippendorff (2012) proposed that the usefulness of this distinction should be questioned as all reading of symbolic matter is qualitative because of the level of interpretation used. The aim of the content analysis is to explore the data in order to uncover patterns of responses that can be categorised into groups or themes in order to reduce the data to a more manageable size. According to Krippendorff (2012) content analysis introduces a number key components to be conducted. These include:

- unitising – defining relevant units;
- sampling;
- recording/coding the data in order to explore the occurrence of the units identified;
- reducing the data to manageable representations in order to summarise or simplify the data;
- abductively inferring contextual phenomena;
- narrating the results of the research questions.

Importantly, the job of the researcher is to identify the units of analysis. These can be categories, concepts or themes that appear in the data. Once the units have been identified the researcher then uses these units to reduce other data produced by the study. The process is not, however, linear and the researcher should undertake a constant comparison between the units initially identified and those that arise from the data in order to check for validity and reliability and to ensure that the results drawn from the study are a true representation of the data (Krippendorff, 2012, Schreier, 2012).

Within science education research, content analysis is perhaps one of the most widely used approaches for analysing data. One reason for this is that it permits the researcher to explore the data that may be unique to their study and to uncover the units or categories and themes that are most relevant within the context of their study. Chi (1997), for example, produced one important paper that was designed to provide researchers with guidance for how to approach analysing children's ideas drawn from research interviews. Within the context of this study a content analysis

approach was taken in order to capture children's ideas in electricity and floating and sinking. Whilst important frameworks have already been identified by previous research studies (e.g. Havu-Nuutanan, 2005 and Borges & Gilbert, 1999), the first stage of the data analysis for Research Phase 2 was to compare and see if further frameworks not yet identified were found within the sample. The rationale for this was based on the unique qualities of both the research approach adopted here and the sample investigated. Previous research has generally paid more attention to verbal language and other multiple-method techniques than to gesture. However, this work would also systematically utilise a content analysis approach to exploring the underlying meaning contained in children's gestures in order to investigate whether these can be helpful for helping to identify children's ideas. In order to support the analysis of gesture, some guidance for data transcription and analysis was drawn from multimodal research.

### 5.4.3 Developing an Approach to Data Transcription and Analysis

Using guidance from previous research (for example Taylor, 2006; Kress, et al., 2001) the transcription of the data from Research Phase 2 was achieved by attending to two modes or forms of communication, the visual and the verbal. According to multimodal research it is typical to transcribe across three conditions with each condition adding to the layers of meaning captured (Jewitt, 2011). These three conditions are visual and verbal together, then verbal dialogue in isolation and finally the visual responses in isolation (Jewitt, 2011). Previous research has suggested that by transcribing in this way it is possible to limit interference between the two modalities and thus provide a comprehensive transcript of the data. As the study generated a large corpus of data the researcher used the first level of transcription to purposively sample specific areas within the videos that contained details that were rich enough to require a full three layered transcription (see Table 11 for further details of the data generated during the study).

<b>Topic: Electricity</b>			
<b>Age Group</b>	<b>Total Number of Video Files (Note 2 cameras per group)</b>	<b>Location of Participants</b>	<b>Number and Size of Groups</b>
Y2	10	Village Primary School	4 x groups of 4 1 x group of 3
Y2	2	City Independent School	1 x group of 15
Y6	12	Village Primary School	5 x groups of 5 1 x group 3
Y6	2	City Independent School	1 x group of 16
Y9	10	Village Secondary School	2 x groups of 4 1 x group of 3 2 x group of 2
<b>Topic: Floating and Sinking</b>			
Y2	10	Village Primary School	4 x groups of 4 1 x group of 3
Y2	2	City Independent School	1 x group of 15
Y6	12	Village Primary School	4 x groups of 5 2 x group of 4
Y6	2	City Independent	1 x group of 14

		School	
Y9	10	Village Secondary School	1 x group of 4 2 x groups of 3 2 x group of 2

*Table 11: Details of all the groups of children taking part in Research Phase 2 and the resulting video files.*

This approach permitted the researcher the opportunity to reduce the data to a more manageable size and the opportunity to exclude data, for example, off-topic social conversations between the children that were not directly relevant to the study. In order to establish an appropriate analytical approach for the multimodal analysis it was important to review strategies that had been previously used by others to explore both audio and video data. For this work it was important to capture a wide range of response types including verbal language but also incorporating analyses of non-verbal responses including gesture. Therefore, it was important to adopt an approach that would permit the accurate comparison of these response types. Transcription of the audio-video recordings of the science activities was the first step undertaken in the qualitative data analysis. Powney and Watts (1987) have suggested that transcripts of such data are useful as a means of verifying the knowledge demonstrated by participants. However, as with all research, it is important to note that the selection of extracts for inclusion is a filtration process and this can lead to omission of valuable information that may alter the context of the findings. The judgement and discretion of the researcher exercised when selecting such extracts for subsequent reporting limits the significance that these may have (Denscombe, 1998). As well as picking out appropriate quotations that demonstrate the levels of understanding that children demonstrate the analysis consisted of a content analysis in order to generate descriptive data.



#### 5.4.4 Multimodal Analysis

Multimodal analysis is a relatively new approach to analysing video and audio based research media (Jewitt, 2011). The method is specifically designed to capture communication and meaning making across the multiple routes of expression. These routes include speech, gestures, whole body movements, gaze direction during interaction with others, writing, pictures and manipulation of objects. Importantly it is proposed that action, visual and linguistic resources available during communication and interaction work in together in order to develop meanings. In science education, such a method was developed from an ESRC funded research project investigating the rhetorics of science classroom (Kress, et al., 2001). It is proposed that because communication takes place across these multiple modes by transcribing and analysing each of these features it is possible to collect a more comprehensive or 'thicker description' of communication (Taylor, 2006). This approach to analysis attempts to reveal more detail than is permitted by analysing language in isolation or offered in the rudimentary analysis of situation offered by conversation analysis or the basic level of non-verbal detail accessible in discourse analysis (Goodwin & Heritage, 1990; Gee, 1999). Unlike discourse analysis (Gee, 1999) this method requires that the researcher transcribes the multiple domains separately on a time-logged transcript. In effect the resulting data includes individual columns so that running concurrently with all articulations details of all non-verbal communication are also recorded (see Table 12 for an excerpt drawn from one of the Year 8 pilot studies completed in Research Phase 1, *RS=researcher*).

Time	Person	Verbal Report	Gesture	Other non-verbal
	RS	Ok, so I would like you to have a think for me about things that float and things that sink, ok (pauses) right, ok, so what do you think floating is?		Two of the children put their hands up
0:34	Tom	Something that doesn't go under water		
	RS	Ok		Looks at Julie who has her hand up
	Julie	It rises above the surface		
	Steven	Erm, yeah	Waves his arm backwards and forwards and then places both hands on the table	Smiles at Julie and then turn to face Tom before lowering his gaze to the desk
0:45	RS	When you say it rises above the surface what do you mean?		Looks at Julie
	Steven	I know...	Waves his index finger at shoulder height	
	Julie	Erm...		Hesitates and looks away from the researcher to Steven
	Steven	It stays on the top		Places his elbow on the table leaving his hand at face height, lowers the left side of his face into hand
	Steven	And erm...its stay on top of the water	Uses his left index finger to trace a path across the water level in the transparent bowl that is present on the table	

*Table 12: An excerpt from a Year 8 pilot study transcript showing all the different levels of communication captured in order to illustrate the importance of different responses types.*

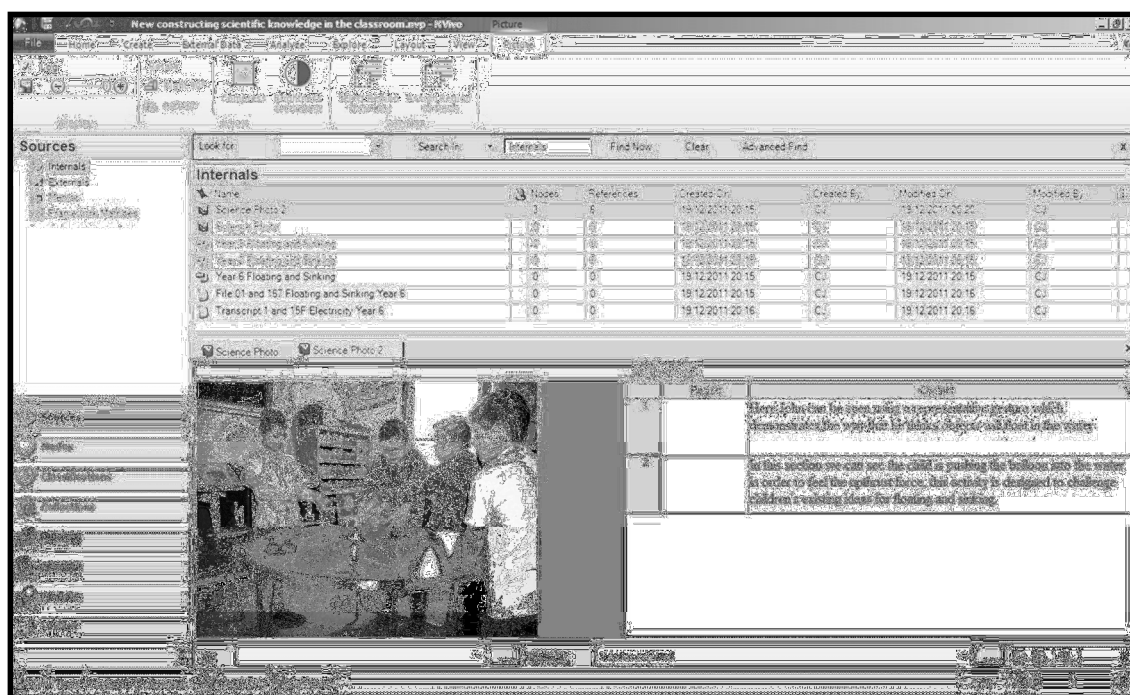
The formation of the transcript permitted the researcher to analyse all forms of communication used at any one time, thus making it possible to identify where the domains are consistent and where inconsistencies arise. This approach therefore

aimed to capture some of the components necessary if gestures were to be analysed for their interaction with verbal meanings expressed during scientific enquiry. As with all methodological approaches multimodal analysis has its strengths and limitations. The key methodological disadvantages of this approach depends on the way in which data are collected, clearly it is advantageous to audio-video record all of the activities of interest but this results in substantial ethical issues regarding the use, storage and publication of data (Goldman, et al., 2007). The multiple layers of transcription required for the subsequent analysis can be very time consuming and require that care is taken in order ensure that each of these layers are drawn back together appropriately for their subsequent interpretation. As with all research methods, multimodal analysis is open to researcher bias in the collection, coding, and interpretation of the data (Jewitt, 2011). Finally, as this method is currently under development the approach is still establishing an appropriate analytical framework and as yet there is no clearly defined approach to transcribing gestures and non-verbal behaviour.

Despite the limitations, however, it is clear that the multimodal approach to data analysis permitted the level of detail required in order to address the research questions. Therefore, the current research adopted an approach to qualitative data analysis that utilised the multimodal approach where the responses across the communication types, language, writing, drawing and gesture, were interpreted for their meaning and compared. As discussed previously (see Table 11) in order to keep track of the large corpus of data generated by this work specialist research software (NVivo 9) was used in order to code the transcripts drawn from Research Phase 2. It was important for the researcher to maintain a clear picture of the way in which children were using gestures throughout the science activities, and what if anything these could add to an understanding of conceptual change therefore incidents of the five different categories of gesture identified in the pilot studies were coded using the NVivo software programme. It is important to note here that the researcher remained open to the identification of new categories; however, in all instances gestures observed in Research Phase 2 could be interpreted within those already identified (see Chapters 6 and 7). NVivo can accommodate a range of different electronic file types including audio, video, text, spread sheet, pdf and image files. This was considered to be advantageous as it offered the researcher the

opportunity to capture different types of data in one place and enabled the researcher to utilise this programme in order to explore key aspects of the data, for example, by importing and coding the transcripts it was possible to assess the frequency with which the different types of gesture were used by the children during the two science activities. It also permitted an analysis of whether the types of gesture used varied according to the topic, electricity or floating and sinking. However, in order to successfully develop the NVivo project it was important to pilot this (Bazeley, 2007). This entailed importing text versions of the transcripts, some still images drawn from the video files and some scanned versions of the children's drawings. Piloting demonstrated that the programme was particularly helpful for assessing the prevalence of gestures and for tracking single children through the activities in order to explore whether their ideas appeared to change. The still images were particularly helpful for illustrating examples of the gestures being studied (see Figure 20 for a screen capture of a photograph being coded in the NVivo programme). Importantly, NVivo also permitted the researcher to add notes to important pieces of information such as the images which could be used as a guide for subsequent coding. The researcher's use of the product was sufficiently unique to attract an invitation from QSR to give a presentation on the effective use of the software at the BETT educational exhibition at London Olympia in 2012. Fundamentally, it was proposed that this process of electronic coding enabled the researcher to keep track of data and to more effectively assess the findings of the research project. However, it was important to note that there are some criticisms regarding using electronic software in qualitative analysis that needed consideration. According to Krippendorff (2012), one important disadvantage is that reliability checks are not actually conceivable. Krippendorff (2012) proposes that although different researchers can receive the same instructions on how to code data, these instructions may be interpreted differently. Thus, although it can appear that computer software makes the process of analysis more transparent, it is actually still heavily influenced by the views and beliefs of the researcher. Krippendorff (2012) also proposed that electronic software uses a specific approach to identifying meaning, e.g. that the same word always has the same meaning even in different contexts. Although this criticism is valid, particularly if autocoding and text searches are used, it is suggested that part of the role of the researcher in the electronic coding process is to ensure that such difficulties are overcome and the researcher

can recode accordingly. Despite the difficulties associated with using software such as NVivo, the advantages of keeping control of such a large corpus of data were overwhelming and most coding was accomplished through the use of the software.



*Figure 20: A screen capture of a photograph coded using NVivo during the research project.*

#### 5.4.5 The Storyboarding Approach to Data Analysis

Whilst the NVivo project detailed above was specifically helpful for identifying children's use of gesture it was less helpful for directly comparing how children discussed their ideas across different response types and indeed it was less able to capture important moments of interaction within a single group. According to the literature there are many different techniques that can be used for reducing data in order to make it manageable (Krippendorff, 2012; Shreier, 2012), and so that it is possible to pick out the important aspects of the contents. As one of the aims of this study was to explore the importance of gesture and what this added to an understanding of children's ideas it was important that the different response types

should be analysed side by side. This required these responses to be translated into a framework that facilitated easy and direct comparison of the meaning contained in various forms of communication. In many studies, researchers simply interpret the data for its meaning and use these interpretations in a comparative process. However, because the aim of this study was to draw various levels of fine-grained data into a form that permitted easy comparison over a range of Levels (see Figure 19) a different approach was required. Therefore an analytical approach, which can be best described as storyboarding, was developed.

The storyboarding approach described here entails using the participants' responses to generate groups of ideas that appear to be interconnected. These groups are then drawn out into a visual model (see Figure 21), which aimed to reveal how ideas may have been developed from other ideas and the structures that may lie beneath them. This process was completed for each of the responses, leaving room within each storyboard to show the various response types and how these informed the frameworks attributed to each of the children. Within the storyboards for each group, a first level content analysis of verbal and gesture responses was conducted and the comparison of these two response types was used to assess the presence of a match or a mismatch between them. A total of six storyboards were completed. One for each age group in each science activity (e.g. one for Year 2 in electricity and one for Year 2 for floating and sinking, one for Year 6 for electricity and one for Year 6 for floating and sinking, etc.). The storyboards were used in order to facilitate comparison and address the research questions, particularly as they enabled the researcher to explore whether or not children's ideas had indeed changed during the science activities and they enabled the direct comparison between the content and meaning ascribed to each of the different communication strategies (e.g. language and gesture).

#### **5.4.6 Development of a Timeline Analysis for Networks of Ideas**

In order to explore that way that the children's ideas changed over time during the activities, a timeline analysis approach was developed. This drew on the work of Givry and Tiberghien (2012), who developed something similar for analysing the ideas that children used during physics lessons. In this approach the main ideas that children used were mapped against the time at which they appeared in discussions. Givry and Tiberghien (2012) used these timelines to propose ways that networks of ideas were related to each other and the number of concepts that were available in those networks. In summary these researchers aimed to show the size of the concept networks that children used. This idea for an approach to analysis was further developed for this work but instead of exploring network size, children's ideas were mapped according to the time at which they appeared in order to show when and where new ideas were introduced, whether these were related to previous concepts under discussion or whether these new ideas appeared to exist in isolation. It is proposed that such analysis may help to inform on how concepts change or develop over time. An example of a timeline analysis is shown in Figure 22.

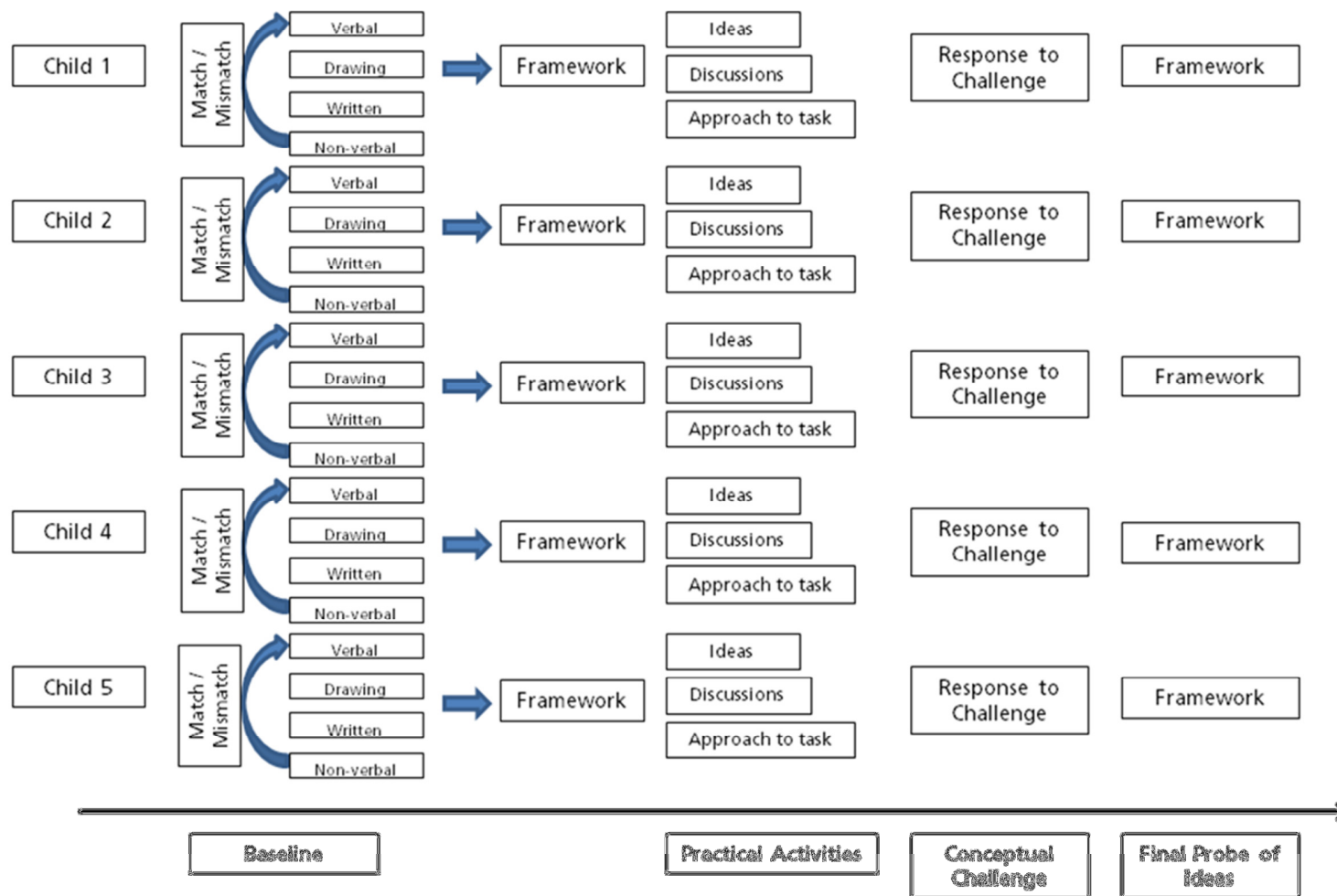
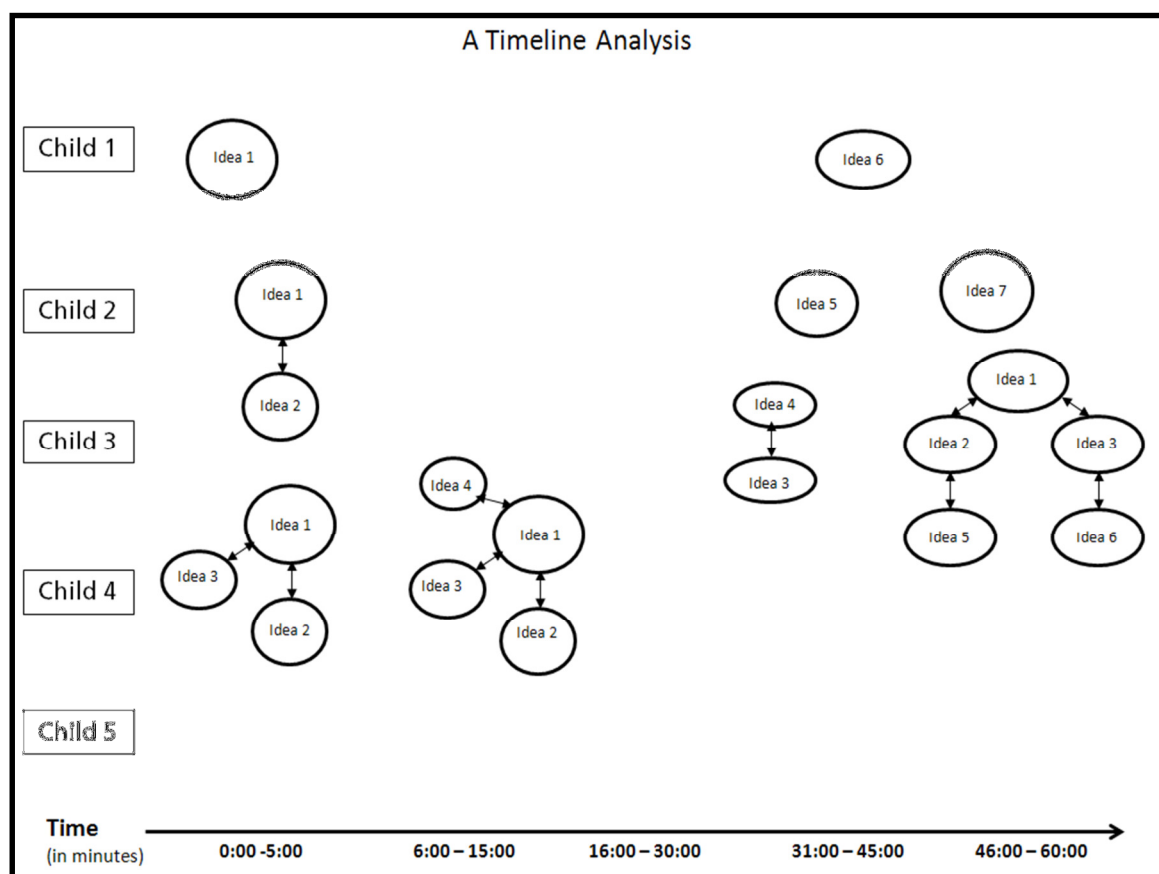


Figure 21: The storyboarding approach to investigating children's ideas within the context of each science activity.





*Figure 22: A basic timeline analysis for the development of new ideas as generated for the electricity results drawn from Research Phase 2.*

According to this timeline analysis Child 1 generates the first idea at the beginning of the activity, this is then added to by Child 2 who proposes another idea but relates this to the first one. Child 4 adds to the timeline by proposing another new idea that is also related by Child 4 to Idea 1 and Idea 2 and so on. It is important to note here that whilst there appears to be blocks of time where no new information is added to the timeline (e.g. between 16:00 – 30:00 minutes). These gaps occur because the children continue to use the same network of concepts highlighted in the preceding timeframe. Importantly, this form of mapping permits the reduction of data to the essential components, e.g. which ideas are introduced, at which point during the activity they occurred and how new ideas were related to those already discussed. Looking at the timeline analysis it is clear that this is reminiscent of the conceptual structures proposed in Chapter 3 (Figures 10, 11 and 12) where previous research had aimed to show the relationships between children's ideas as they changed in light of tuition. Such an exploration was of pivotal importance to this work and this

method of mapping facilitated the researcher to pinpoint possible points of conceptual change, development or growth whilst remaining mindful of the activities that the children were undertaken at each point in time. However, this mapping of concepts was extremely time consuming and this had restricted the application within the current work. In order to highlight the utility of this approach for capturing such data one timeline analysis has been conducted for each of the science topics (one for electricity and one for floating and sinking).

## **5.5 Discussion**

In this chapter the multimodal, task-based approach to studying children's ideas has been discussed in detail. It was highlighted how this approach had been developed from the work contained in Chapter 4. The importance of studying gesture has been revealed by using the analysis of the pilot study data drawn from Research Phase 1 (Chapter 4). These analyses showed that children's gestures in science could be attributed to five categories, each of which had an important role in permitting the researcher to understand children's ideas, and it was also shown that on some occasions these gestures contained details of children's ideas that were not evident in their verbal discussions. Furthermore, the analysis of gesture also showed that it was possible to use these in order to explore some of the social aspects of learning and the way that children used gestures and non-verbal responses in order to elicit help from each other.

The results of Research Phase 1 helped to illustrate the value of using the multimodal approach and provided a framework for transcription that was adopted during Research Phase 2 and 3. This transcription framework included additional columns of data that captured the different types of responses (e.g. gestures and other non-verbal behaviour) in order to show how these were used by the children during the activities. Whilst the pilot studies were important for developing transcription procedures they also highlighted the potential utility of using the NVivo 9 research software in order to code the large corpus of data generated by Research Phase 2. Importantly, the results of the pilot studies also highlighted that it was important to develop an analytical framework specifically for capturing all of the levels of detail generated by the different response types (e.g. verbal response and

gesture). This chapter introduced the development of such an analytical approach which facilitated the direct comparison of these responses using a storyboarding technique. The storyboarding approach provided a visual mapping of children's ideas as they developed throughout a single activity and it also permitted effective data reduction. Finally, this chapter also included details of the development of a timeline analysis approach to exploring the development of children's ideas during the practical science activity. The aim of this form of analysis was to track how ideas were related to each other and to pinpoint points of change should they arise. In the following two chapters this thesis will explore the results of the Research Phase 2 which probed and challenged children's ideas for electricity and floating and sinking.

## Chapter 6 Children's Ideas about Electricity: a Multimodal Perspective

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### 6.1 Introduction

In this chapter the analyses of and the findings from the electricity activities are presented and discussed. The results are structured according to both 'conventional' approaches to studying children's ideas and the new multimodal, task-based approach.

In the first part of the chapter the analyses explore the content of the children's drawings and written and verbal responses during interview. These are analysed using a 'conventional' approach. In all cases content analyses were undertaken on the children's individual worksheets (as discussed in Chapter 4) and the group transcripts drawn from the electricity practical activities. These examinations of the underlying frameworks of understanding that the children were using when discussing their ideas and structured around:

- completing a simple circuit diagram showing how a bulb lights;
- describing what electricity is;
- considering the properties of materials that conduct electricity.

In the second part of this chapter, different aspects of the multimodal analyses are presented. Following transcription, the data were coded using NVivo in order to complete the multimodal analysis. NVivo offered a particularly powerful platform for this analysis by drawing together the transcripts from multiple cases and making it possible to trace coding across and within transcripts as discussed in Chapter 5. This more detailed level of analysis permitted the identification of the different types of gestures that children used as well as indicating the prevalence of these across the three age groups. In order to explore the utility of the storyboarding approach detailed in Chapter 5, three group studies were conducted. Each group study was

transcribed in full and the comparative analysis between the different response types was completed by hand rather than through the use of NVivo. These storyboard analyses explored the ways that the children used different response types (e.g. drawings, written, verbal and gestures) in order to show their understanding during the activities and the way that the children's ideas changed (if at all) during the course of the activities. Finally, in order to show how ideas developed during a single activity a timeline analysis was completed for one of the Year 9 groups. This groups' data were transcribed fully and coded by hand in order to capture the transition between the concepts that children were discussing during the activities. Finally in this chapter, the results of the activities are compared to previous research and the importance of studying gesture is assessed using the data collected during Research Phase 2.

As highlighted in Chapter 3, electricity is well studied in the research literature and is also embedded within the National Curriculum for Key Stages 1- 4, the materials taught appearing in Physical Processes but also overlapping with Materials and Their Properties in Key Stage 2 and above (DfEE & QCA, 1999). According to the guidance:

- Key Stage 1 – pupils are taught that everyday objects use electricity, simple circuits using batteries, bulbs and wires and the effect that a switch can have;
- Key Stage 2 – pupils are taught that some materials conduct electricity, how to construct series circuits (including how changing components influences the circuit e.g. brightness of the bulb), how to represent circuits in drawings using the symbols for electrical components;
- Key Stage 3 – pupils are taught that electrical current in circuits can produce a variety of effects, the particle model is introduced and pupils receive tuition in series and parallel circuits including the concepts of current and voltage;
- Key Stage 4 – pupils are taught that electrical power is readily transferred and controlled and can be used in a range of situations.

In National Curriculum terms, children's learning is measured according to Attainment Targets which consist of 8 level descriptors of increasing difficulty, plus a description of what exceptional performance would be. The attainment levels for each topic are available from the Department for Education. According to the DfEE and QCA (1999), children are expected to attain the following levels at the following ages (Table 13):

Range of levels within which the great majority of pupils are expected to work		Expected attainment for the majority of pupils at the end of the Key Stage	
<b>Key Stage 1</b>	1-3	<b>At age 7</b>	2
<b>Key Stage 2</b>	2-5	<b>At age 11</b>	4
<b>Key Stage 3</b>	3-7	<b>At age 14</b>	5/6
<b>Key Stage 4</b>	National qualifications are the means of assessing attainment		

*Table 13: The range of levels children are expected to work within and the expected attainment for the majority of pupils at the end of the Key Stages.*

The presence of Electricity in the curriculum highlights that all of the children involved in this study will have received some form of tuition prior to undertaking the activities here.

## 6.2 Traditional Approach to Analysing Children's Ideas

As detailed in Chapter 4, the following participants were recruited for the electricity activities undertaken as part of Research Phase 2:

- 19 children in Year 2 at Village Primary School;
- 15 children in Year 2 at City Independent School;
- 28 children in Year 6 at Village Primary School;
- 16 children in Year 6 at City Independent School;
- 15 children in Year 9 at Village Secondary School.

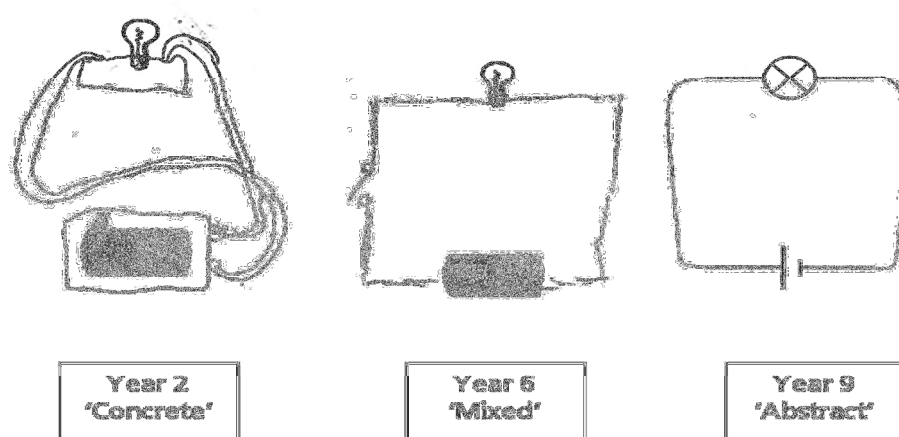
The children completed the electricity activities as detailed in Chapter 4, section 4.6. In summary these activities entailed the children first taking part in a baseline test for their ideas about electricity. This included a discussion of what they thought electricity is, and drawing and sentence completion tasks. The children then moved on to build simple, series and parallel circuits during which time their ideas were continually probed. They also discussed how electricity is measured. This was followed by a problem solving activity where the children were asked to group materials (including cork, plastic, metals such as copper and steel and different types of wood) according to whether or not they thought that they would conduct electricity, to develop an effective means of testing the materials, and then discuss their results. Children's existing ideas were challenged using an analogy with chocolate smarties to represent electrons moving in a circuit. The story of Alessandro Volta's invention of the battery was also discussed before the children took part in a final probe of their ideas. The researcher led all activities by way of the dialogic teaching method which probed the children's ideas and provided tuition using the analogy. Throughout the activities the researcher used a participant observation approach in order to judge the appropriate time to ask specific questions and in order to assess when the activities should be moved on.

In order to explore the way that the children's ideas changed between the three age groups of children, a comparison of the features of children's drawings was undertaken. This was followed by an analysis of the content of their written work and an analysis of the content of their verbal responses.

### **6.2.1 Children's Drawings**

In order to explore the children's understanding of electrical circuits, all participants were asked to complete a simple circuit diagram. As in the pilot studies, in order to decide which children should be given the worksheet containing the abstract electrical symbols and which children should be given pictorial representations of the battery and bulb they were first asked if they could identify the symbols that are used when normally discussing electricity. Worksheets were allocated accordingly. In all cases the Year 2 children completed the circuit diagram on the worksheet which

contained pictures as none of these children could reliably identify the symbols. The two worksheets were relatively evenly distributed in the Year 6 groups and all of the Year 9 children completed the worksheet with symbols. All children were asked to sketch in the connecting wires in order to 'make the bulb light'. A qualitative content analysis of children's circuit completion drawings was conducted in order to explore how these varied between the age groups. In all cases and across all age groups the children successfully completed the circuit diagrams (see Figure 23). However, not all drawings of a complete circuit were accurate and 15% (N = 5) of the Year 2 children placed the wires inappropriately (e.g. not connected to the poles of the battery).



*Figure 23: Typical circuit drawings as completed by the three age groups investigated in this project.*

The drawings themselves revealed a number of different styles and these showed variation across the age groups. The younger children (Year 2) had a tendency to sketch bulb and battery holders into their drawings; they also frequently tried to draw 3D representations of the wires. The Year 6 children sketched wires using straight single lines in accordance with the symbols used to represent electrical components even though many of these children completed the worksheet containing the battery and bulb pictures. Interestingly in this age group the children frequently included switches in their diagrams, of the children who did this 5 sketched in the appropriate symbol for a switch whilst the other 5 drew in a switch that was located in the closed



position. When probed about this, the children answered that the switch was important because it enabled them to turn the light off and on; however, they all agreed that a switch did not have to be in the circuit in order to make the bulb light. The Year 9 children represented the wires in a rectilinear circuit in accordance with the abstract symbols used for electrical components. In this age group only one child included an additional symbol and this was inconsistent with the symbols that are typically used to represent electrical components (Figure 23). The drawings shown in Figure 23 are all scientifically correct, however, they appear to move from a concrete representation, where children draw exactly what they see to an abstract representation, where the children produce drawings using the accepted circuit diagram conventions. The content of the children's drawings is summarised in Table 14.

Age	Incomplete Circuit	Complete Circuit		Complete Circuit with Additional Features	
		Wires inappropriately placed (e.g. wires not touching the positive or negative poles of the battery)	Wires appropriately placed (e.g. wires touching both battery poles)	With a switch drawn in the closed position or with other components (e.g. motor)	With a switch drawn using the accepted symbol
<b>Year 2</b> (N = 34)		5 (15%)	27 (79%)	2 (6%)	
<b>Year 6</b> (N = 31*)			21 (68%)	5 (16%)	5 (16%)
<b>Year 9</b> (N = 15)			14 (93%)		1 (7%)

*Table 14: The distribution of different aspects of children's circuit drawings across the three different age groups of participants. (\* Some children from this age group did not complete the drawing task.)*

As shown no children who participated in the activities drew an incomplete circuit, this was expected as prior to participation all children had had some form of tuition in electricity. The features of the circuits drawn became more scientific as the age of the participants increased and none of the Year 9 children produced drawing which

contained inaccuracies such as the wires not being appropriately placed or the switch being drawn in the closed position.

## 6.2.2 Children's Written Responses

Following the drawing exercise, children were asked to individually complete a sentence to explain why the bulb in their drawing would light. Qualitative content analyses of the written responses generated by the children across the three age groups were used in order to generate a framework system of ideas. Notably, only 16 (47%) of the younger children were able to complete the written response to the task. Outcomes are presented in Figure 24. A range of ideas were uncovered for why children thought that the bulb would light, these included, because there is a battery, the wire has electricity in it and battery power goes into the wires and causes it to light. Interestingly, the majority of the responses produced by the children in this age group discussed specific elements of the circuit rather than the role of the circuit in its entirety.

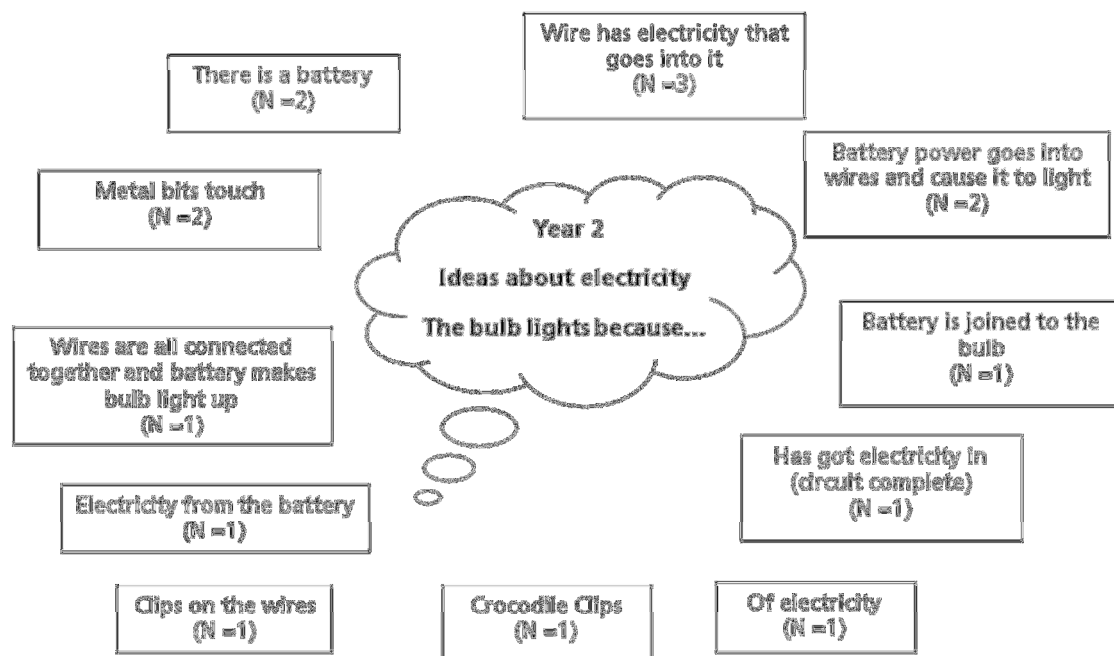


Figure 24: The different written explanations that Year 2 children (7 years of age) gave for why the bulb lights (16 from 34).

It is proposed that responses such as the bulb lights because “the metal bit touch”, provides a good example of a concrete concept where the children are using directly observable phenomena in order to explain the results. In contrast responses such as “battery power goes into the wires and cause it [the bulb] to light” provide examples of concepts that are more abstract, the child cannot directly see the power pass from the battery to the wires but they do appreciate that this is what makes the bulb light. Ideas in this age group appear to be much more intuitive rather than scientific although there is some evidence of an appreciation of scientific qualities.

Similarly, only 19 children (43%) in Year 6 gave written responses when asked why the bulb lights. Figure 25 presents an overview of the reasons given. These included, because the circuit is complete, the battery sends power to the bulb and electricity from the battery is carried by the wire. Written comments in this age group revealed that children had begun to focus more on the interactions within the circuit as whole and these were given greater importance. However, some children still focused on single features of the circuit rather than the whole.

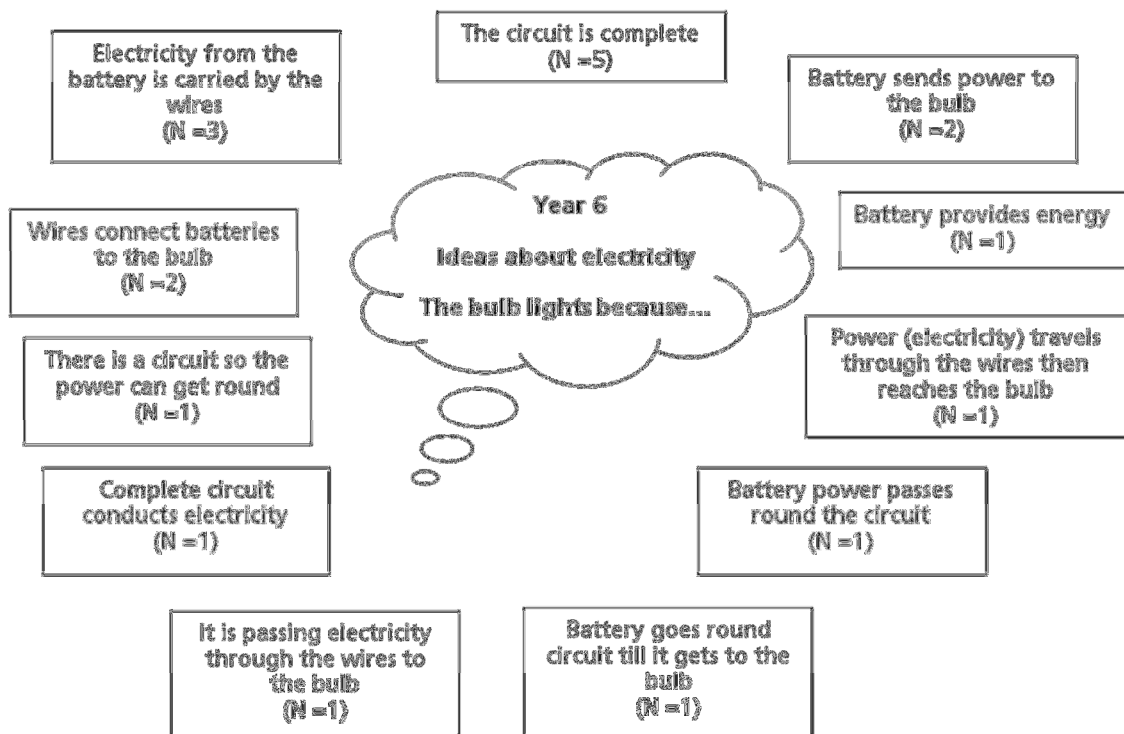


Figure 25: The different written explanations that Year 6 children (11 years of age) gave for why the bulb lights (19 from 44).

As before there was evidence of some concrete examples being used in the Year 6 children's written responses, these included "the circuit is complete" and "wires connect batteries to the bulb". These examples appear to show that even in Year 6 some children still focus on the directly observable features of the circuit rather than what may be happening inside of it. In contrast, there was also evidence of abstract concepts such as "power (electricity) travels through the wires then reaches the bulb" and "battery power passes round the circuit". In both of these examples the children appear to be drawing on ideas that are not readily observable in electricity tasks. As with the Year 2 children, there is mixed evidence of both intuitive and developing scientific ideas in the Year 6 children's responses. For example, some children state that the battery sends power to the bulb but they do not appear to be aware of how this happens, in contrast another child states that the complete circuit conducts electricity. The idea of conductivity represents a more scientific concept and shows how these older children's ideas are beginning to correspond more closely with tutored concepts of electricity.

All 15 (100%) of the children in Year 9 provided a written response to the sentence completion task. Typical responses at this age included battery power travelling through the wire to power the bulb, the wires connect to the bulb, and energy from the battery is sent through the wires to the bulb. Figure 26 presents an overview of all responses provided. The majority of children in this age group focused their written comments on the circuit as a whole interacting system and only 3 children now focused on small components in the circuit (e.g. the wires connecting to the bulb). As with the younger children there was still some evidence of concrete concepts being discussed such as “the wires connect to the bulb”, this showed that even in Year 9 some children were still relying on directly observable features of the circuit in order to support their ideas. There was however, also evidence of some abstract concepts. For example, one child stated that the bulb lights because “electrical current can pass through the bulb and get back to the battery”. This particular response represented a good example of an abstract concept which showed the child’s awareness of factors that were not directly observable. In terms of types of concepts as with the other children there was evidence of both intuitive and scientific concepts. One example of an intuitive concept was “the wires connect to the bulb”. This concept appears intuitive because it only acknowledges surface details such as the connections of the different elements in the circuit. An example of a more scientific concept can be drawn from the child who states “electrical current can pass through the bulb and get back to the battery”. This statement acknowledges the requirement for all parts of the circuit to be connected and also acknowledges that the current continues around the circuit after it has passed through the battery.

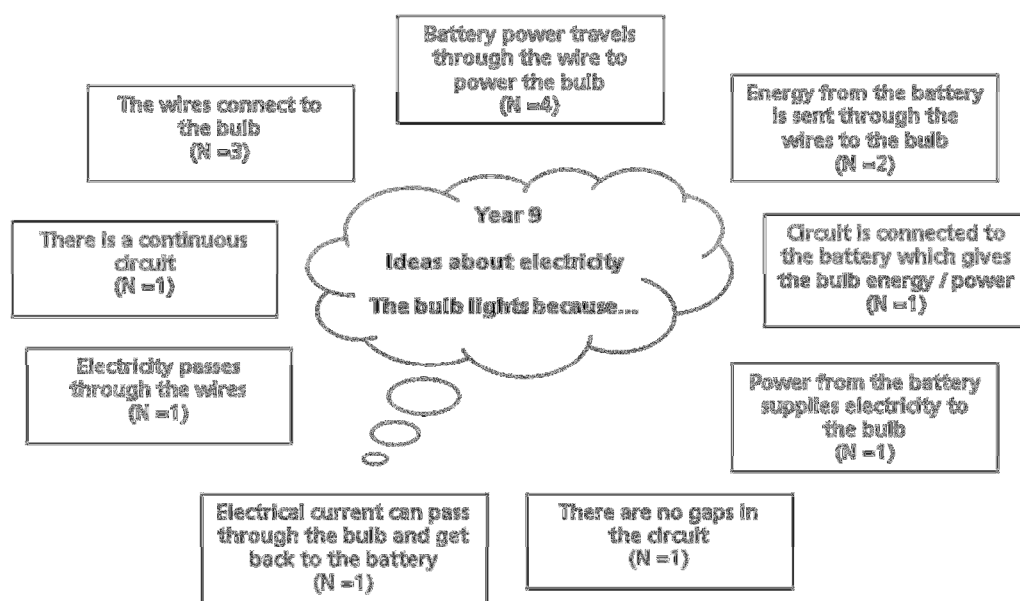


Figure 26: The different written explanations that Year 9 children (11 years of age) gave for why the bulb lights (15 from 15).

Overall, the results of the analysis of the written responses revealed that the older children were more able or confident in writing their ideas about why the bulb lights. This may have occurred because the writing competencies of the children or because the younger children found it more difficult to express their ideas in this way. As anticipated the older children used more scientific concepts in their discussions, and in fact the written responses reveal the slow transition between intuitive and scientific concepts and the transition between children thinking in concrete terms (e.g. based on what they can observe) to thinking in abstract terms (e.g. where the children appreciate aspects that are not readily observable). These results suggest that over time and with greater exposure to learning opportunities about electricity the children's ideas evolve to become more like the scientific explanations, however, even the oldest children still do not have a full understanding about what electricity is and they still used concrete concepts at times.

### 6.2.3 Children's Verbal Responses

In order to explore children's ideas further during the interviews their verbal responses to the following questions were recorded for analysis:

- What do you think electricity is?
- What do you think is happening in the circuit in order to make the bulb light?
- What do you think would happen when different electrical components were added to a circuit?

In the first instance a thematic analysis for the terms used to describe electricity was undertaken. The results of this analysis revealed that in the younger children (Year 2) electricity was almost always viewed as a form of power. By Year 6, some children still referred to electricity as a form of power but others began to talk about electricity as a form of energy. In addition some children discussed ideas of flow and atoms. The Year 9 children stated that electricity was a source of power or energy but in addition, at this age, the notion of current was prominent in some children (see Table 15). Overall it can be suggested that the themes present in the youngest children's verbal responses represent concrete concepts, e.g. that electricity makes things work. This effect of electricity is directly observable and the idea that electricity is a form of power is intuitive. There is evidence of ideas becoming more abstract in some of the Year 6 children's response and these include themes such as "electricity is something to do with atoms", although it can be difficult to pin down exactly what the children understand by this, such responses reflect a clear shift in thinking from concrete concepts to those that are more abstract and not directly observable. Similarly, the Year 9 children show a further move towards more scientific and abstract concepts and 4 children (27%) discuss the notion of electrical current during the baseline assessment.

<b>What is electricity? Themes</b>	<b>Year 2 (N = 34)</b>	<b>Year 6 (N = 44)</b>	<b>Year 9 (N = 15)</b>
<b>Makes things work</b>	8 (24%)	10 (23%)	
<b>A form of power</b>	19 (56%)	19 (43%)	
<b>Source of power</b>	7 (20%)		4 (27%)
<b>Atoms</b>		5 (11%)	
<b>Is energy</b>		10 (23%)	3 (20%)
<b>Power and Energy</b>			4 (27%)
<b>Current that powers things</b>			4 (27%)
<b>Flow of electrons</b>			

*Table 15: Themes drawn from children's discussions of what electricity is.*

Verbal responses to the probes for what the children thought would happen when different components were added to the circuit and why they thought this would happen were coded according to the frameworks of understanding for electrical circuit discussed in the work of Borges and Gilbert (1999). It is important here to note that Borges and Gilbert worked with professionals and based this initial framework on the previous research identified in Chapter 3. Borges and Gilbert's outcome categories are presented as shown (Table 16). Looking at these categories it is clear that ideas allocated to category one would contain the most intuitive and least scientific concepts, whilst category 7 would contain the most scientific. Importantly, Borges and Gilbert (1999) added to the scientific model (category 7) in their work, these additional categories were not required in this work as the participants were significantly younger and had less experience of working with electricity.

The results for the frameworks that children held across the different age groups are shown in table 17. Interestingly these results also demonstrate a clear developmental shift in the frameworks held with older participants demonstrating the more scientific models. None of the children held non-relevant or non-scientific models, this may have occurred because at the time that the research was undertaken all of the children had received some form of tuition in electricity concepts.

	Primary Framework	Category
Intuitive ----- → Scientific	<b>Non-Relevant and Non-Scientific</b> No relevant properties are mentioned or the responses are not relevant to electricity	1
	<b>Unipolar Model</b> There is a flow of electricity from the battery to the bulb; the electricity is all used up by the bulb. The second wire is not necessary / seen as required to light the bulb but plays no active role in the circuit.	2
	<b>Two-Component / Clashing Currents Model</b> 'Plus' and 'minus' currents travel from the battery terminals to the bulb where they meet and produce energy	3
	<b>Closed Circuit Model</b> All the circuit elements have two connections, current circulates around the circuit in a given directions and the circuit only functions when the switch is closed. The model recognises the	4



	bipolarity of circuit elements but it suggests that the current is not conserved. Lack of differentiation between current and energy	
	<b>Current Consumption / Sequence Model</b> Current is described through a series events, current is consumed as it goes through the circuit components, though a fraction of it returns to the other end of the battery	5
	<b>Constant Current Source / Sharing Model</b> The battery is seen as a source of constant current, e.g. the current supplied is always the same regardless of the circuit features. It is recognised that the battery wears out with time. According to this model, two bulbs share the current whether they are connected in series or parallel	6
	<b>Ohm's / Scientific Model</b> A current flows around the circuit transmitting energy, current is conserved and differentiated from energy. Circuit is seen as an interacting system and a change at one point in the circuit affects the entire system	7

Table 16: The frameworks identified by Borges and Gilbert (1999).

The clashing currents model was the most predominant framework that the Year 2 children held at the beginning of the activity, whilst the closed circuit model was most predominant in both the Year 6 and Year 9 children. These results appear to match the experiences of the children and it could be suggested that models 5, 6 and 7 are all more advanced than would be anticipated for these ages of the children. Typically, these results appear to similar to those produced by the previous research into children's ideas about electricity as detailed in Chapter 3.

	Category	Year 2 (N = 34)	Year 6 (N = 44)	Year 9 (N = 15)
Intuitive ----- Scientific	<b>1</b> Non-relevant and Non-Scientific			
	<b>2</b> Unipolar Model	4 (12%)	5 (11%)	
	<b>3</b> Two-Component / Clashing Currents Model	21 (62%)		
	<b>4</b> Closed Circuit	9 (26%)	39 (89%)	15 (100%)

	Model			
	<b>5</b> Current Consumption / Sequence Model			
	<b>6</b> Constant Current Source / Sharing Model			
	<b>7</b> Ohm's / Scientific Model			

*Table 17: The frameworks of understanding for what happens in a circuit applied by the three age groups (Year 2, Year 6 and Year 9) measured at beginning of the activity.*

In order to further explore children's ideas about electricity all children took part in problem solving activities, during this activity they were asked to sort a range of materials according to whether they thought that they would conduct electricity and then design and implement an appropriate approach to testing the materials (see Chapter 4 for further details). A qualitative, cross-age comparison of children's understanding of electrical conductivity was undertaken. This comparison utilised evidence drawn from both the accuracy with which the children categorised materials according to whether they would conduct electricity and children's discussions of the factors that they believed influence a material's ability to conduct electricity. The results suggested that children's ideas used to explain the conductivity of materials does become more scientific over time as children become older. Measures revealed a high degree of accuracy for predicting conductivity was evident across all three age groups. All groups correctly identified that metal objects typically conduct electricity. However, there were some significant inconsistencies. Many Year 2 and 6 children thought that a glass marble would conduct electricity. No Year 9 children predicted this outcome. Children in Years 2 and 6 often thought that a transparent disk of plastic would conduct electricity. This never occurred in the Year 9 children. In addition, many Year 2 and 6 children thought that a two-pence coin would not conduct electricity, whilst children in Year 9 frequently cited this material as a good conductor because it was the same material that wires were made of. Preliminary

analysis of the reasons why children thought some materials conduct electricity revealed that at Year 2 children frequently stated for example, '*metal things always let electricity pass through*'. In addition, they explained that the glass marble and the transparent plastic disk would let electricity through because they were able to see through it. When probed children were unable to suggest any reasons why this occurs. By Year 6, children's responses revealed an evolving conception suggesting that some thought conductivity had something to do with what the material was like inside, but when probed they remained uncertain as to why this might be. The Year 9 children, whilst including all of the explanations given by the other age groups, suggested that conductivity might also be linked to the way in which particles were arranged in objects.

#### **6.2.4 A Comparison between Children's Drawings, Written and Verbal Responses**

A comparison between the drawings, verbal and written responses for the children was conducted. This revealed that all children were able to produce an accurate representation of circuit in their drawings; however, their verbal and written responses revealed a wide range of different ideas about electricity. This suggests that although it was relatively easy for children to produce such drawings with a high degree of accuracy such tasks do not accurately reveal their underlying ideas for what electricity is or how it works in isolation. A comparison between the verbal responses that children generated when asked why the bulb in a circuit lights revealed that for the younger children (Year 2) there was a disparity between the content of their verbal responses and the content of what they had written if they had written anything at all. The Year 2 children always produced accurate drawings, frequently provided detailed and well developed verbal responses even though they had been unable to do so in writing. Notably in their verbal responses the children frequently discussed all of the different components in the circuit and their importance in order for the bulb to light. A similar effect was evident in the Year 6 children who were also able to complete circuit diagrams more abstractly but often failed to respond to the written probe. However, by this age the written responses that were provided more frequently contained a more detailed description of the need for a complete circuit in order to make the bulb light and the different

components that are important in order to make the circuit work. Interestingly, although by this age children often added components such as switches into their drawings these additional components never appeared in their written responses. Year 9 children had the most advanced drawings and always presented a written response to the probe on the worksheet. Furthermore these responses were often more detailed and almost always indicated the necessity for a complete circuit as was evident in their verbal responses. Interestingly, by this age some children discussed the role that electrons play in an electrical circuit but this term never appeared in their written responses.

Overall the results of the traditional approach to exploring children's ideas revealed that the frameworks that children become more scientific as they get older, the content of drawings become more abstract over time and uses less concrete pictures in order to represent elements of a circuit. As children become older, and perhaps more confident in writing, they are more likely to produce more advance written responses to probes and the children's verbal response also become more well developed and scientific overtime. These results are consistent with the previous findings of Shipstone (1985), Osborne, et al. (1991) and Borges and Gilbert (1999) (detailed in Chapter 3).

### **6.3 Changing Children's Ideas**

As the electricity activity included a conceptual challenge element, the demonstration of the movement of electrons in a circuit, a thematic analysis was conducted for the children's ideas of what electricity is at the end of the activity and the overall frameworks that they had applied. The results revealed that the younger children remained fairly consistent in their discussions; there was little evidence of additional or new ideas being incorporated when they stated what they thought electricity is (see Table 18). Strikingly however, the Year 6 and Year 9 children had begun to incorporate the term 'electrons' into their ideas about what electricity is (20 in Year 6 and 8 in Year). These children had not previously referred to electrons in their discussions (see table 18). The results presented support the notion that the children were making progress in their ideas after participating in the activities.

What is electricity? Themes	Year 2 (N = 34)		Year 6 (N = 44)		Year 9 (N = 15)	
	Before	After	Before	After	Before	After
Makes things work	8 (24%)	12 (35%)	10 (23%)			
A form of power	19 (56%)	15 (45%)	19 (43%)			
Source of power	7 (20%)	7 (20%)			4 (27%)	4 (27%)
Atoms			5 (11%)			
Is energy			10 (23%)		3 (20%)	3 (20%)
Power and Energy				24 (55%)	4 (27%)	
Current that powers things					4 (27%)	
Flow of electrons				20 (45%)		8 (53%)

*Table 18: The themes drawn from the children's verbal responses to what electricity is at the beginning and the end of the activities.*

When exploring these changes in more depth it was also evident that a large number of the Year 6 children had begun to use the word energy into their discussions, this term had also not been evident at the beginning of the activity. These results appear to support the view that the structure of the practical science activity was useful for challenging children's ideas, particularly when they were older. However, it is important to consider that a study such as this one does not permit the researcher to explore whether the revisions in ideas were the result of a long term change in conceptual structure or an immediate reference to a relevant feature that may be later forgotten. In order to further explore any possible changes in the children's ideas about electricity the framework analysis was again completed using the evidence drawn from the entirety of the activities, e.g. what children thought electricity was, what they thought would happen when circuits were changed, what they thought would happen in a parallel circuit, ideas about conductivity and ideas at the end of the session following conceptual challenge. The results of this comparison are presented in table 19.

	Category	Year 2 (N = 34)	Year 2 (N = 34)	Year 6 (N = 44)	Year 6 (N = 44)	Year 9 (N = 15)	Year 9 (N = 15)
		Before	After	Before	After	Before	After
Intuitive -----> Scientific	<b>1</b> Non-relevant and Non- Scientific						
	<b>2</b> Unipolar Model	4 (12%)	1 (3%)	5 (11%)			
	<b>3</b> Two- Component / Clashing Currents Model	21 (62%)	21 (62%)		1 (2%)		
	<b>4</b> Closed Circuit Model	9 (26%)		39 (89%)		15 (100%)	
	<b>5</b> Current Consumption / Sequence Model		9 (26%)				4 (27%)
	<b>6</b> Constant Current Source / Sharing Model		3 (9%)		42 (96%)		8 (53%)
	<b>7</b> Ohm's / Scientific Model				1 (2%)		3 (20%)

*Table 19: The frameworks of understanding for what happens in a circuit applied by the three age groups (Year 2, Year 6 and Year 9) measured at beginning and the end of the activities.*

These results revealed that many of the children had changed the frameworks that they were applying when discussing electricity. As with the theme analysis the most significant changes appeared in the Year 6 Year 9 children, with their ideas appearing to develop into more scientific conceptions as the activities progressed. However, it is important to note that many of the changes in the frameworks used did appear after the children added bulbs to their series circuits. This finding supports the view that it is extremely difficult to allocate children to specific frameworks as

their ideas do appear to change and evolve with the task demands. Notably, with the additional bulb more Year 2 children use the more advanced scientific models in their explanations, e.g. 9 (26%) children now applied the sequence model whereby the current is consumed as it goes through the different components of the circuit. Similar results were evident for the Year 6 children with 42 (96%) now applying the sharing model. Finally, it was only through adding the additional bulbs to the circuit that there was evidence of the oldest children (Year 9) using the most scientific models.

Overall, however, there is evidence that by using a conceptual challenge approach such as detailed in these activities it is possible to change the ideas that children have particularly if they are older. These changes do appear to take place on two distinct levels, for the older children the changes are at theme level and the children are more likely to incorporate the more advanced concepts in their later discussions. Changes also appear to occur at framework level, with all children, but perhaps more significantly the older children, showing evidence of changes at theory level. Importantly, it can be suggested that whilst it is easy for children to produce circuit diagrams that are scientifically accurate this actually tells the researcher little about their underlying understanding of electricity. The depth of probing and the range of activities used in the sessions discussed here however, did reveal that children do not apply their ideas about electricity consistently, they do instead apply them based on the task demands and can move between frameworks of understanding accordingly. This makes it extremely difficult to state with certainty what frameworks the children actually do hold and if they have learned from a specific incident unless the probes are thorough enough to pick up all aspects of the children's knowledge.

The results of the traditional analyses of the children ideas appear to demonstrate that children's ideas for electricity do become more scientific over time and between the three age groups with the oldest children demonstrating evidence of the most scientific models. For example, the oldest children produced drawings that took the form of the circuit diagrams that could be found in text books whilst the youngest children attempted to represent the 3 dimensional shapes that the circuit components held. In the children verbal and written work the Year 9 children demonstrated awareness that electricity is a form of energy that powers things or

describing it as a current. The Year 6 children discuss electricity in wide range of different ways including stating that it is form of power or that it is energy. The youngest children (Year 2) tended to state that electricity is a form of power that makes things work.

The analysis exploring whether it was possible to change (or begin to change) children's ideas through the conceptual challenge aspect of the methodology showed that the youngest children failed to respond to these prompts even though they showed evidence that they were able to understand what electrons were during the role play, the Year 6 children did show evidence of changing conceptions and begin to incorporate terms such as energy and electrons into their descriptions of what electricity is. Finally, the Year 9 children also demonstrated evidence of changing ideas and incorporated the term electrons into their final discussions.

#### **6.4 New Approaches to Studying Children's Ideas about Electricity – Multimodal Group Studies**

In order to explore what the multimodal analysis of data can add to the discussions and debates regarding the processes that support conceptual change three groups were purposively sampled from the entire corpus of audio / video data. One group was selected from each age studied and groups were sampled according to whether the participants used gestures within their discussion. As almost all of the children gestured at some point during the activities, sample groups were drawn from those where the gestures appeared to perform an important role in the children's discussions (e.g. gestures were used to support, complete or elaborate on verbal explanations when the children were talking). In order to gain a balanced view, these group studies included examples where changes were evident following the challenge of children's ideas, examples where no change was evident and examples where the activities did not progress as anticipated. It is proposed that by taking this approach the analyses presented here are particularly representative of typical classroom activities where there may be great levels of variability in the outcomes



that result from teaching and the other factors that can impact on learning. A total of three group studies for electricity were produced: Year 2, Year 6, and Year 9.

In all instances the group studies chosen for further analysis were transcribed fully. In order to reduce the data to a manageable level a storyboard was produced for each group, these storyboards captured key events within the activities, important ideas and discussions that the children had and the frameworks of understanding for the electricity that were evident at the beginning and end of the activity. The storyboard was also used to highlight 'critical moments' where the discussions between the participants appeared to have an impact on the children's learning or where the different modes of communication played an important role in either communicating children's ideas or where there was contrast between the content of both modes. The critical moments identified during the storyboard analysis were subjected to transcription across three conditions; sound only, image only, sound and image together. However, firstly in order to explore the importance of gesture this section explores the prevalence and types of gestures that the children produced.

#### **6.4.1 Children's Gestures for Electricity**

The gestures that the three age groups of children produced when discussing their ideas for electricity were also analysed. As this analysis required an additional level of detail the baseline and end of activity probes of all of the group activities were transcribed and analysed and the full content of the three group studies (discussed later in section 6.4) were used. The results revealed that the children did use the five categories of gesture proposed in Chapter 5:

- referential;
- representational;
- expressive;
- thinking;
- social.

The prevalence of these categories of gesture is shown in table 20. The analysis revealed that within the context of the electricity activity referential and representational gestures were used the most frequently across all of the age groups of the children. However, there was also evidence of expressive, thinking and social gestures occurring within the context of these activities even though these gestures occurred less frequently.

<b>Types of Gesture</b>	<b>Referential</b>	<b>Representational</b>	<b>Expressive</b>	<b>Thinking</b>	<b>Social</b>	<b>Total</b>
<b>Year 2</b>	38	33	6	8	15	102
<b>Year 6</b>	21	48	18	4	31	122
<b>Year 9</b>	23	15	4	5	15	62

*Table 20: The frequency of occurrence for the different types of gestures across the three age groups of children.*

When exploring the differences between the age groups it appeared that the Year 2 children used the most referential gestures in their discussion, frequently these included pointing to objects rather than naming them. The same age group also used representational gestures frequently, these tended to be when the children used their hands to act out or represent objects or actions. Such use of representational gestures may have occurred because of the complexity of the language required to explain some aspects of their understanding of electricity. The Year 6 children used representational gestures more frequently than any other age group and any other form of gesture. As with the Year 2 children these gestures often comprised of the children using their hands to represent objects or actions. This age group also appeared to use social gestures more frequently, and although this may have been a feature specific to this group of children the social gestures were often used in order to offer support to each other. Finally, the Year 9 children most frequently used referential gestures, including pointing. As with the Year 2 children, these gestures often referred to objects that the children did not name.

In order to highlight how the gestures were used the following analysis provides some examples of typically occurring gestures that children used when talking about

electricity. Overall, the children frequently used referential gestures to refer to various components both within the drawings that they had completed and within the circuits that they had made and sometimes they used other objects to make these gestures. In our first example, Liam, a Year 9 boy, used a referential gesture in order to show the symbol for a bulb on his drawing (image 1, Figure 27).

Time	Person	Verbal Report	Gesture
03:27	RS	Okay, so can I ask you then, what do you think is actually happening in that circuit to make the bulb light?	
	Liam	The energy from the battery is being passed through the wires to the light which makes it light up.	As he speaks Liam bounces the pencil between his thumb and index finger, when he says light he points to the symbol for bulb that is on his paper and then continues to bounce the pencil between his thumb and index finger again.

*Table 21: Extract from a Year 9 transcript which shows Liam using a referential gesture to point to the symbol for bulb in his drawing in order to support his discussion of what happens in a circuit in order to make a bulb light (RS = researcher).*

Examples of such referential gestures were consistent across all three age groups. Similarly, there was a high prevalence for representational gestures. These representational gestures often consisted of drawing paths which represented the movement of electricity in circuits. In one example two Year 6 participants, Alex and Lena, used circular path movements in order to represent the ‘flow’ of electricity. At this point in the activity the children had made a simple circuit and were discussing the behaviour of electricity, both children demonstrated an awareness that electricity moves in a continual motion around the circuit (image 2, Figure 27). It is proposed that this gesture enables us to have a clear understanding of how these children think that electricity moves but their verbal responses are also revealing and they

enable us to see that although the children have an idea about how electricity travels they do not attempt to define its nature.

Time	Person	Verbal Report	Gesture
03:27	RS	Does it stop at the bulb though or does it go somewhere else afterwards?	
	Alex	No it keeps...	As Alex speaks he uses his right index finger to draw a circular path over the top of his circuit.
	Lena	It just keeps travelling round.	As Lena speaks she draws a circular path over the top of her circuit with her right index finger.

*Table 22: An abstract from a Year 6 transcript demonstrating how two children use the circular representational gesture in their discussions of the movement of electricity in a circuit (RS = researcher).*

Although representational and expressive gestures were the most commonly occurring, expressive gestures were also frequently used by the children. As previously identified in the pilot studies expressive gestures were used by children in order to show the strengths of values such as a responses.



*Figure 27: A referential, a representational and an expressive gesture drawn from the Research Phase 2.*

Expressive gestures came in many forms and appeared to be strongly linked to the accompanying verbal discussions that children provided; however, they appeared to represent values that children found difficult to describe in language. The following examples drawn from the transcripts demonstrate how children used this form of gesture during the electricity activities. In the following extract, Selena, a Year 2 child, was discussing her ideas for why a bulb in the circuit diagram that she has just completed would now light (image 3, Figure 27). Her expressive gesture captured how she thought light behaved when it was emitted from the bulb in the circuit, it is proposed that she used her fingers to represent the light and by spreading them as wide as she could she represented the way in which this light would be visible from the bulb.

Time	Person	Verbal Report	Gesture
05:45	Selena	I know, the electricity comes out of there, forces through the crocodile clips and lights up the bulb, and all these like sparks come out.	As she speaks Selena points to the picture of the battery on her drawing, then to the wire, then to the bulb. As she says sparks she lifts both of her hands into the air and spreads her fingers as wide as they can go then lowers them back to the top of the table.

*Table 23: Selena, a Year 2 child used an expressive gesture to represent the behaviour of light which is emitted from a bulb in her circuit drawing.*

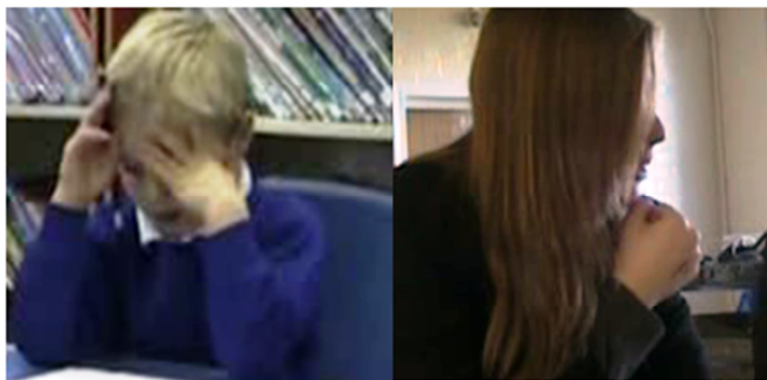
Expressive gestures such as this one may be valuable for providing insight into how the children think certain things will behaved. However, one important finding from both the pilot studies and the main data collection phase was related to the importance associated with knowing when children were ready or not to move on with discussions. This was sometimes possible to ascertain through the thinking gestures that the children produced. As previously discussed thinking gestures are particularly important cues that can be used in order to judge whether or not

discussions should be moved on or whether children should be given more time to respond. Throughout the activities there were a number of incidents when the children used thinking gestures during their discussions. In the first example shown in Table 24, Mike, a Year 2 participant, was discussing his ideas for why the bulbs get dimmer when, he began with the verbal utterance of ‘well’ and then he raised his hands to his forehead before looking down at the top of the table (image 1, Figure 28). Shortly after Mike begins to speak again, but this gesture is proposed to represent a non-verbal cue that he needs a moment to consider his ideas before he is ready to verbalise them.

Time	Person	Verbal Report	Gesture
05:37	Mike	Well...	As he starts to speak he puts both hands to his forehead and then looks down to the table.

*Table 24: Mike, a Year 2 child, using a thinking gesture to signal that he requires some time to consider his ideas before he can respond to the researcher’s probes.*

Whilst thinking gestures can be helpful for knowing when to move on with discussions other forms of gestures, social gestures, were used by the children in order to elicit social support as well as signify agreement with other group members. In the example presented here a social gesture is shared between Janet and Noel, Year 9 participants, as they discuss which materials act as insulators.



*Figure 28: An example of a thinking and a social gesture drawn from Research Phase 2.*

Whilst Janet names different materials Noel points to them on the desk, Janet acknowledges this and nods to him (image 2, Figure 28). Noel's pointing behaviour appeared to have two functions; firstly it was used in a referential manner to illustrate what Janet was referring to and secondly it can be interpreted as providing social support for Janet's ideas because Noel was showing a form of agreement. Janet's nod acknowledged Noel's addition to her discussion.

Time	Person	Verbal Report	Gesture
09:03	Janet	Rubbers and plastics.	Nods to Noel as he points to the materials.

*Table 25: Year 9 child Janet uses a social gesture to acknowledge the support that Noel has given her throughout the activity.*

These results of the analysis focusing on gesture show support for the notion that studies of gesture are important if we are to understand all aspects of children's ideas. The gestures discussed here do appear to have an important role in the children's communication strategies. In addition, it is proposed that these gestures reveal aspects of the children knowledge and understanding that is not contained in their other response types. For example, the representational gestures used often include details of how children thought electricity moved in a circuit, such discussions never appeared in their verbal or written responses to probes of their understanding. Such gestures may also reveal underlying mental processes, for example,

representational gestures are frequently used to show how objects or processes behave and this may be a form of embodied cognition where the knowledge of the process is held in the physical action rather than a verbal explanation, such an interpretation would be consistent with the work of Karmiloff-Smith (1992, see Chapter 3). Furthermore the gestures do appear to offer a window into the children's problem solving activities, how they work with others and socially negotiate concepts as well as revealing something about their learning.

#### **6.4.2 Year 2 Group Study**

This group study focused on a group of four children (three female, one male) called Lisa, Tara, Selena and Mike from Village Primary School. The activity lasted approximately 40 minutes. The activity was held in the school library area which contained two large round tables. The children were encouraged to sit around one of the tables so that they could build their electrical circuits. The group had been defined by the Year 2 class teacher in the school. The teacher had asked the researcher how she would like the children to be grouped and at the researcher's request had allocated the children so that each group contained a range of different academic abilities. The group worked well together and frequently engaged each other in discussion. This particular group actually demonstrated little change in their ideas about electricity following the conceptual challenge aspect of the practical activity. However, all of the children in this group used gestures at some point during the activity and the gestures that they did use sometimes appeared to contain conceptual knowledge and other important features that was not evident in their speech or from other tasks.

The initial analysis presented here focuses on the multimodal representations that children brought when first discussing their ideas about electricity. Storyboard 1 (see Figure 29) details the ideas contained within the content of the children's drawings, their verbal responses to probes of their knowledge, their written responses to the sentence completion task and the gestures that they used as they talked. An analysis of the content of their drawings revealed that all four children are able to complete the task by drawing in the wires in order to make a complete circuit. It is



proposed that these drawings contain information that goes beyond their verbal responses as they clearly show that the children also had awareness that in order to make the bulb light they must make a complete circuit with wires connecting the battery to the bulb. However, for two of the children the wires were inappropriately placed, notably they were connected to the middle of the battery rather than to the end of the battery. It could be suggested that by drawing in the wires in this way the children's awareness of the importance of connecting wires to each pole of the battery was not yet firmly established. However, it could also be proposed that these drawings may just represent a careless completion of the task where the children paid little attention to the small details such as where the wires should be connected. In addition, one of the children, Mike, also drew in a battery holder. This inclusion may perhaps draw on his previous experiences of making circuits in the classroom where the children generally use a battery pack in order to make connecting the wires easier.

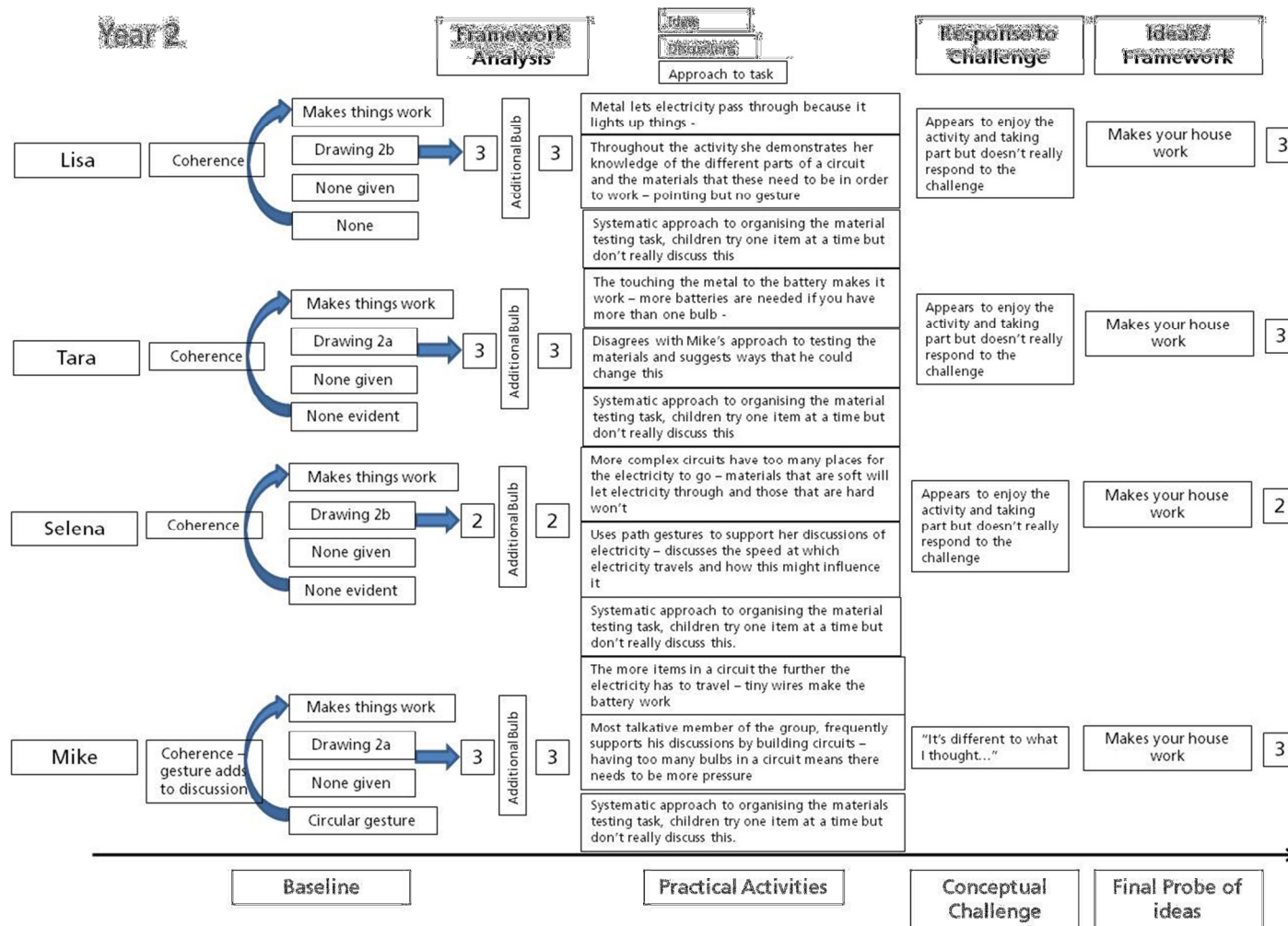


Figure 29: The storyboard from the Year 2 children's electricity activities.

None of the children in this group provided a written response to the sentence completion task but they did offer verbal responses when probed (we will return to a discussion of these later). All of the children agreed that it was important for the wire to run from the battery to the bulb and then for another wire to run back to the battery to complete the circuit. All of the children agreed in their verbal responses that electricity ‘makes things work’. Interestingly, this particular group of children frequently gestured throughout the activity and at the first probe of ideas for electricity Mike uses his hands to produce a circular gesture (see Table 26 and Figure 30). It is proposed that this circular gesture may show one of two things, firstly, the circular gesture may refer to Mike’s underlying knowledge of how the lights in the school are connected in a circuit. Alternatively, Mike’s gesture may represent an understanding of how the electricity moves in a circuit. It is proposed that either conclusion would demonstrate that Mike has an awareness of a circuit that is not verbally expressed and it is important to note that at this stage in the activity this concept has not been introduced and it does not appear in any of the children’s verbal responses.

Time	Person	Verbal Report	Gesture
00:55	Mike	Erm it helps you, say if this whole room was dark and if you wanted the lights to turn on you would have to have electricity.	As he speaks Mike uses his right index finger to make a circular gesture in the air.

*Table 26: Mike’s circular gesture which is proposed to detail his understanding of a circuit even though this idea is not present in his verbal response.*

With the exception of one child in this group, Selena, the children all appeared to hold a ‘clashing currents’ model for electricity (Osborne, et al., 1991; Borges & Gilbert, 1999). Selena, at least initially, appeared to hold a ‘Unipolar’ model as her discussions focus on the electricity travelling from the battery and ending at the bulb (Osborne, et al., 1991; Borges & Gilbert, 1999). In this particular group there was no evidence of the framework of understanding changing according to the task specificity when the additional bulb was added, the children’s models appeared to be applied consistently throughout the activity and indeed as shown in storyboard 1 (Figure 29), the children did not revise their ideas at the end of the activity after they have completed the conceptual challenge aspect of the task. However, Mike, did

acknowledge that the conceptual challenge contained information that was different from what he had thought although it is difficult to provide additional information as to what he meant by this.



*Figure 30: Mike's representational gesture from Table 26, Lisa's representational gesture from Table 27 and Mike's referential gesture from Table 28.*

As discussed earlier, this particular group of children frequently used gestures throughout the activity and often these gestures reinforced their verbal discussion or contained additional knowledge that is not conveyed in their verbal responses. A few key examples are illustrated here. In our first example Lisa was discussing the types of things that use electricity. She suggested that boats are sometimes electric, as she says this she uses both of her hands to produce a representational gesture in order to show the boat (see transcript extract in Table 27 and Figure 30).

Time	Person	Verbal Report	Gesture
01:47	RS	What kind of things do you think use electricity? You've already talked about lights but what else uses electricity?	
	Mike	When you want boats to move.	
	Tara	Cars.	
	Lisa	Sometimes you have electric boats.	As she says this Lisa holds her right hand out flat in front of her with her palm facing upwards as she finishes speaking she places her hand

			back on her knee.
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*Table 27: Lisa uses her hands to represent a boat in order to support her verbal discussion.*

It is proposed that Lisa's gesture was used to support her verbal discussion and serves as a representation of the boat that she was discussing. The gesture had a clear introduction and ending and allowed the onlooker to visualise Lisa's intended meaning, notably the way that Lisa held her hands allowed us insight into how she thought the boat will behave in the water. In another example, Mike was discussing how he thought a bulb holder was important in order to make the bulb in his circuit diagram light. He uses the end of his pencil to point the bulb in the picture in order to clarify his intended meaning (see transcript extract Table 28 and Figure 30). Although Mike's verbal discussion proposed that a bulb holder was needed his pointing gesture indicated where it would need to be placed in the diagram in order for it to be effective. After Mike had finished speaking he went on to draw in the bulb holder at the location that he had specified. It is proposed that pointing gestures such as these helped to add to participants intended meaning as they provide an anchor to objects or locations in the external world.

Time	Person	Verbal Report	Gesture
04:18	Mike	Wouldn't you need like a bulb holder?	Points to the bulb on his picture using the end of his pencil.

*Table 28: Mike's pointing gesture used to show where a bulb holder would need to be placed in his diagram.*

In the following example, Tara used a two handed gesture to demonstrate knowledge that is not readily available in her verbal response. Indeed her two handed gesture which demonstrates how she thought the electricity flows from both sides of the battery to the bulb allows us to categorise Tara's ideas about electricity within the 'clashing currents' model (Osborne, et al., 1991; Borges & Gilbert, 1999), whilst her verbal response "*because the power comes that side and that side*" is fairly ambiguous (see transcript extract Table 29, Figure 31). This type of path

gesture used to represent the movement of electricity in a circuit was fairly typical within the corpus of audio-video data.

Time	Person	Verbal Report	Gesture
06:19	Tara	Cuz that wire needs to go that side and that wire needs to go that side because the power comes that side and that side.	As she speaks Tara uses the end of her pencil to point to the battery pack and the wires on the drawing, she then draws two paths one from either side of the battery to the bulb.

*Table 29: Tara's referential gesture used to clarify how she thinks electricity moves in a circuit.*

As well as using gestures to communicate understanding, some children used the physical activity of building the circuit during their discussions of their ideas. It could be suggested that these occur by chance but in the following example Mike deliberately dismantled his circuit and rebuilt it as he discussed his ideas (see transcript extract Table 30, Figure 31). It is unclear whether this action was to support Mike as he discussed his idea or whether the physical act of building the circuit was more personal and used to support Mike's access to his knowledge.

Time	Person	Verbal Report	Gesture
09:28	Mike	The batteries are working. You connect all of the wires to the stuff that you need to make to, and then you need to have two of these (wires with crocodile clips) and then you connect both of these to there and then you need to see if the battery works and then you just put two, both of them on there and then it comes out.	As he talks about how to make the circuit Mike takes apart his working circuit and then puts it back together, as he gets to the end of his explanation he finishes the circuit and the bulb lights up.

*Table 30: Mike dismantles and then rebuilds his circuit as he discussed his ideas about what is happening in his circuit in order to make the bulb light.*

Clearly within this group of children, gesture and the physical act of holding objects and building circuits appeared to play an important role in the children's discussions. Thus it is proposed that an analysis of gesture alongside the analysis of verbal

responses is fundamentally important if we are to understand the ideas that children have. In addition to the analyses of gesture, the storyboard summarises some of the important discussions and ideas that the children had during the activity. For example, when discussing why the bulbs become dimmer when more are added to the circuit, Mike proposed that this occurred because the electricity had to “travel further”. Selena, further suggested that the more complex circuits had “too many places for the electricity to go”. It could be suggested that these discussions contained more advanced knowledge of electricity than is permitted within the electricity models introduced and that these discussion allude to an early conception of resistance and the way that this may impact on how the electricity travels around the circuit. This example demonstrated the complexity of the ideas that these children have and interestingly it appears as though Mike and Selena provided a supporting environment for these complex discussions where one child introduced an idea and another builds on it. Discussions of this complexity may not have occurred if this project had approached investigations of children’s ideas from the conventional single participant interview approach.



*Figure 31: Tara’s referential gesture Table29, Mike’s rebuilding his circuit as he discussed his ideas Table 30 and Mike holding the wire while he discussed his ideas about conductivity Table 32.*

The group study also permitted the opportunity to explore the children’s approaches to conducting a scientific investigation. The material sorting task, which was used to explore which materials the children thought would conduct electricity was particularly illustrative of the children’s knowledge of a using a scientific approach in their work. All of the children adopted a systematic way of testing the materials for

conductivity. They tried one item at a time and then drew their conclusions from this testing. It is interesting to note that the accuracy of the children's predictions were variable. Mike thought that a sponge ball would conduct electricity whilst Lisa was adamant that only metal objects would conduct. Despite this clear disagreement between the participants regarding the objects, the children did not engage in debate, they simply listened to each other's ideas then expressed their own. Selena offered a particularly interesting comment when she proposed that materials that are soft would let the electricity pass through whilst materials that are hard would stop the electricity. When asked to clarify why she thought this Selena replied that things that are soft would not break (see transcript extract Table 31).

Time	Person	Verbal Report	Gesture
21:54	Selena	Things that are soft will let it go.	
	RS	Why do you think that?	
	Selena	Cuz they are not hard and things that are soft will cuz it is just so so so so soft that it won't break.	

*Table 31: Selena proposed that soft objects will let electricity pass through.*

It was clear at this point that Selena had expressed her ideas as deeply as she could at this stage and that it was time to move the activity on. Despite the contrasting views regarding which materials will conduct electricity none of the children showed surprise at the items that did and none of the children referred back to their earlier predictions. Following the testing of the materials the children proposed that all metal things let electricity pass through and when asked why they thought that the children indicated that it was because switches are made out of metal (see transcript extract Table 32, Figure 31).

Time	Person	Verbal Report	Gesture
31:29	RS	Okay what is it about metal then do you think that lets electricity pass through?	
	Mike	Ooh, metal it's sometimes erm switches are made out of metal cuz electricity its, fits it, the wire goes through the pass and then it goes into the light.	Mike holds a wire in his hand as he discusses his ideas.

*Table 32: Mike discusses his ideas for why metal conducts electricity.*



Taken as a whole, this particular group study illustrated the importance of the multimodal analysis for facilitating a more holistic understanding of younger children's ideas. The analysis of drawing enabled the researcher to explore awareness of the structure of a circuit even though these were not evident in the verbal and written responses given. Having an awareness of the content of children's gesture was also important as these frequently permit the researcher to access a deeper understanding of children's ideas, their thinking, and problem solving ability and learning. Notably, it was through an analysis of gesture that it was possible to clearly differentiate between which frameworks of understanding about electricity the children held, for example, it was only by analysing gesture that it was possible to identify that Tara held a 'clashing currents' model. This group study also helped to demonstrate how the storyboard analysis can be used to collect a summary of complex data.

### **6.4.3 Year 6 Group Study**

The Year 6 case study focused on five children (three female, two male) called Rachel, Alice, Sophie, Peter and John from Village Primary School. This group study lasted approximately 45 minutes. The activity took place in the school library which contained two large round tables and the children were grouped around one of the tables so that they had a flat surface on which they could build their circuits and so that they could work together with ease. The group had been defined by the class teacher and at the request of the researcher contained a range of different academic abilities. The group worked well together and frequently collaborated in order to generate ideas and to support each other in the completion of the tasks. An overview of this case study is available in the storyboard 2 (Figure 32).

In the children's initial discussions of what electricity was this group of children identified that they thought that electricity "*powers things*". What was interesting was that as Sophie said this she also used a circular gesture which accompanied her verbal response. The circular motion that she used could be interpreted as revealing an underlying understanding for the way that electricity moves in a circuit (see transcript extract Table 33, Figure 33). Alternatively it is possible that the circular

gesture was used to support Sophie's thinking as she talked through her ideas. Whilst we cannot be certain which interpretation is the most appropriate this gesture does appear to be used to support her verbal response.

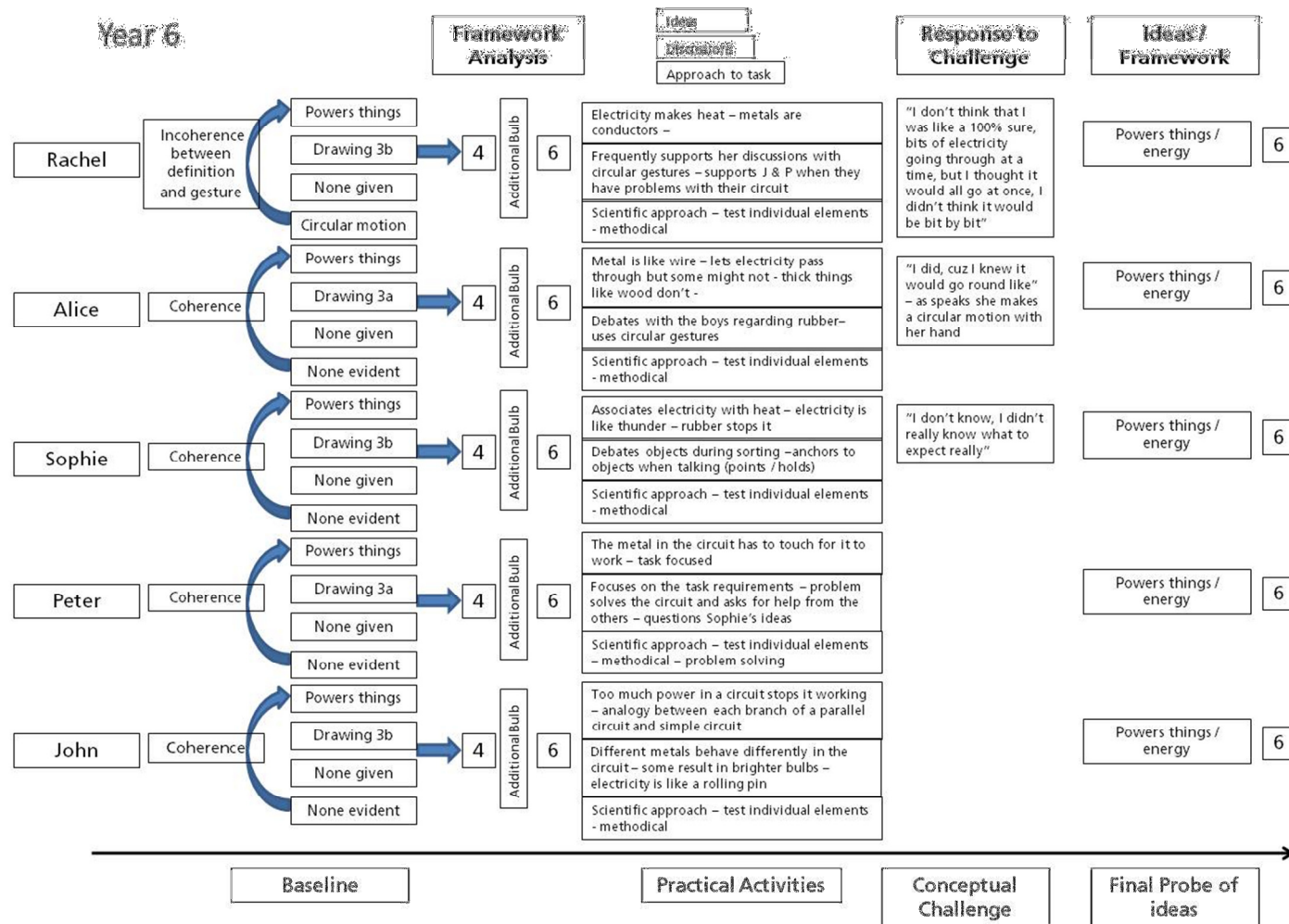


Figure 32: Storyboard from Year 6 electricity activities.

Time	Person	Verbal Report	Gesture
00:16	Sophie	Electricity is what powers things like phone and things like that.	As Sophie speaks she uses her right hand to make a circular waving motion.

*Table 33: Year 6 child Sophie uses a circular gesture as she discusses her ideas for what electricity is.*

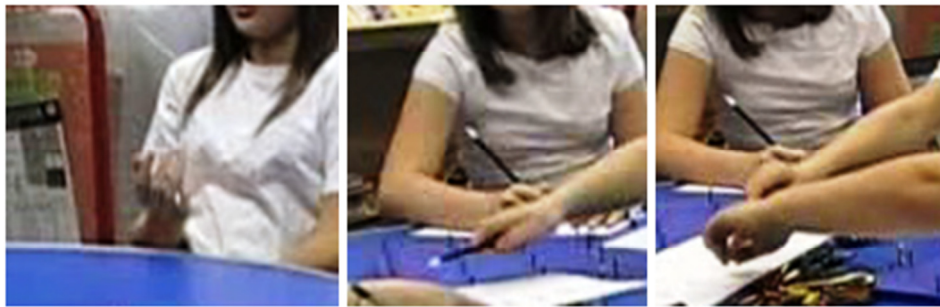
The drawing task that the children completed revealed that all five children were able to generate an appropriate circuit diagram (e.g. two wires were drawn, one from each side of the bulb and these connected to either side of the battery). This particular group of children were interesting as they specifically asked if they could work together. Once it was confirmed that this was okay the children discussed the task and its requirements and each child's suggestions were acted upon by the whole group. One child read out the instructions and the others all identified elements that would need to be drawn into the diagram in order to make the bulb light. For example, when completing the circuit diagram, Rachel proposed that they needed to add a switch. John highlighted which symbol should be used and Sophie clarified her understanding and then asked the others for guidance regarding where she should put the switch in her diagram. This group were particularly good at producing collaborative work when compared to other groups of children who had participated in the activities. They frequently supported each other during the activity and offered advice to each other on approaches to completing the work (see transcript extract Table 34; Figure 33).

Time	Person	Verbal Report	Gesture
03:54	Alice	<i>Reads from the sheet, Complete the picture to make the bulb light.</i>	
	Rachel	You need a switch.	
	Alice	Wires, we need like wires.	
	Sophie	Should we be talking amongst ourselves?	
	RS	Yes, that's ok.	
	Sophie	Can we have the leaflet please? <i>Referring to the sheet that the researcher has used containing the symbols for electricity.</i>	Sophie points to the piece of paper that she wants.

	RS	Yeah, of course you can.	
	John	The switch is that one.	John uses his pencil to point to the symbol that he thinks he needs to use.
	Sophie	That one?	Sophie uses her pencil to point to symbol.
	John	Yeah.	
	Sophie	So where does that need to go, does it have to go towards the battery?	
	Rachel	It could go there or there.	Rachel uses her right index finger to indicate either side of the battery.

*Table 34: Transcript from the Year 6 case study demonstrating how the group works together in order to support the development of each other's ideas (RS = researcher).*

In this instance, and as expected, all five children added the additional feature of a switch to their circuit diagrams. Interestingly, however, three of the children (Rachel, Sophie and Peter) drew in the symbol for an open switch that they had been taught prior to distributing the worksheets whilst the other two children (Alice and John) drew a switch symbol that was placed in the closed position. It could be suggested that for these two children the awareness that there could be no gaps in a circuit in order for it to work prompted their decisions to draw the switch in this position. Furthermore, the discussion in the transcript extract above provided evidence that both Alice and Peter were less active in the discussion about the inclusion of the switch than the other three children.



*Figure 33: Sophie's representational gesture (Table 33), Sophie's referential gesture and John's referential gesture (Table 34).*

The circular gesture that Sophie produced during the initial probes of the children's ideas about electricity emerged again whilst the children worked through their explanations of what they thought was happening in the circuit diagram in order for the bulb to light. The extract from another transcript (Table 35, Figure 34) shows how both Sophie and John used this circular gesture as they discuss how the electricity moves. It is proposed that this gesture was used to represent the electricity and that as seen in Sophie's response the gesture went beyond the information that was available in the children's verbal responses. What was also interesting about this particular extract is that it shows how these two children collaborated in order to generate an explanation for the movement of electricity that is acceptable to both. Sophie struggled to find the words in order to explain her ideas, John appeared to respond to this and stepped in and offers his own explanation which Sophie then supported.

Time	Person	Verbal Report	Gesture
05:54	Sophie	The switch...like power in the bulb.	As Sophie says this she uses the end of her pencil to draw a circular motion in the air above the table.
	John	Well, the battery like power like goes through the wire, like the electricity from it and lights up the bulb and turns it on when you press it on.	As John speaks he makes a circular motion with his left hand and when he says 'switch it on' he moves his hand, index finger extended and mimes pressing a switch on. Once he has done this he

			uses this left hand to make the continuous circular motion which he only stops once he has finished talking.
	Sophie	That's what I meant.	

*Table 35: An extract for the Year 6 transcript which showed the use of representational gestures to support ideas about electricity and how the children supported each other's discussions.*

This particular group did not produce any written responses to the sentence completion task but this was not unusual for this age group. The framework analysis for the children's ideas about electricity revealed that all five children held 'closed circuit' models for their ideas (Obsorne, et al., 1991; Borges & Gilbert, 1999).



*Figure 34: The gestures used by the children to represent electricity moving through a circuit.*

That is, they all appeared to understand that it is important for all circuit elements to have two connections and that the circuit only operates when the switch is closed. All children appeared to show a lack of differentiation between current and energy. However, once the task was changed and the children were asked to predict what would happen to the bulbs if an extra bulb was added to their circuit they all appeared to use the 'sharing' model in their responses (see transcript extract Table 36).

Time	Person	Verbal Report
09:10	Sophie	But the more bulbs that you have, it won't be a powerful because

		they will be sharing electricity.
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*Table 36: A Year 6 participant discusses what will happen if more than one bulb is added to a series circuit. This response is typical of a child who holds a “sharing” model about electricity.*

Evidence such as this suggests that great care needs to be taken when placing children’s ideas into frameworks as the frameworks used when explaining ideas can be heavily task specific and can appear to be subject to change according to the conditions surrounding the probes. The data suggests that although the conditions may appear to support the notion of change, in actuality the children are just responding to the stimulus and are applying different frameworks according to what they think is appropriate.

As the children worked through the activity this group continued to support each other, for example, John and Peter had been working together in order to build their circuits. At one point during the activity they encountered a problem and their bulb stopped working, Rachel and Sophie offered assistance and tried to help the boys to solve their problem. The girls actively directed the boys to different parts of their circuit and made suggestions for ways that they could fix it. The children collaborated in order to try a new bulb, new wires and a new battery but when they failed to get the circuit to work again they agreed that as a group they will use the working circuit that the girls have previously constructed. During the course of the activity this particular group also widely used gestures in order to support their verbal articulations of ideas and in some cases to reveal information that went beyond the content of their words.

In the next example, John is discussing what he thinks happens in a battery, his gesture described in the third column shows how he thinks electricity in a battery behaves (see transcript extract Table 37, Figure 35).

Time	Person	Verbal Report	Gesture
34:20	RS	Okay then, can I ask you what you think happens inside the battery?	
	Alice	Is it like, it turns or something?	As she speaks Alice rotates both of her hands around



			each other.
	John	Yes, I was about to say that, the electricity is like a rolling pin, it keeps moving, it keeps like spinning round and it feeds the electricity through the wires.	As he speaks John circles each of his hands around each other, as he says 'feeds the electricity' he stops rotating his hands and uses his right hand to point to one of the wires in the simple circuit that is on the table in front of him.
	Rachel	....round.	
	Sophie	Yeah, and that's how it makes the electricity.	

*Table 37: John uses a representational gesture in order to show how he thinks electricity behaves in a battery (RS = researcher).*

The particular gesture in which John demonstrated how he thinks electricity behaves in a battery permitted the identification of information that went beyond the content of his articulation, notably, John proposed that electricity is 'like a rolling pin'. As he said this he used both of his hands to produce a circular motion. This circular motion in which John's hands rotate around each other can be interpreted as showing how he thought the electricity moved around inside the battery until it was fed into the wires of the circuit. A similar gesture to this was first introduced by Alice who proposed that the electricity in the battery 'turns or something', this articulation was accompanied by her rotating each of her hands around each other. The idea that electricity rotates inside the battery before it fed out into the wires was supported by the other children in the group and Sophie could be seen to add verbal support at the end of the transcript extract.



*Figure 35: Alice and John's representational gestures (Table 37).*

In another example John used referential gestures in order to add clarity to his verbal response. In the transcript extract (Table 38, Figure 36) John pointed to different items in his circuit in order to locate the objects that he was referring to. It is important to note that without the inclusion of the gesture in this discussion it would be difficult to know exactly what John was referring to when he discussed “that metal bit”. Referential gestures such as these are fundamentally important for facilitating a good understanding of the children’s ideas and the children frequently made these non-verbal links between their articulations and objects that were present in the room.

Time	Person	Verbal Report	Gesture
09:35	John	It travels from that metal bit to that metal bit.	As John speaks he first points to the metal clip at the side of the battery, then to the metal clip at the side of the bulb, then to the metal on the opposite side of the bulb.

*Table 38: John, a Year 6 pupil, used a referential gesture in order to locate objects that he was discussing.*

Within this group of children a number of interesting discussions arose as the children worked through the activity. A few are highlighted here and in the storyboard for this group study. Firstly, Rachel proposed the notion that electricity generates heat, this idea is supported by Sophie who later extended this idea to include the notion that there can be too much power in a circuit and that this can stop the bulbs from working. In the children’s discussions of materials that they thought conduct electricity it was suggested metals are the best conductors. Alice proposed that this is because “metal is like wire”, however, she also acknowledged that some metal may not work. In addition to this idea that metal is the best conductor, Alice proposed that “thick” items such as wood may not conduct electricity because they don’t have any wires in them whilst Sophie proposed that “rubber stops electricity”. The children sorted the materials with a high degree of accuracy, one exception being the piece of rubber which Sophie proposed stops electricity, Peter was uncertain of this and asked her to confirm how she knew that to which she replied that she just remembered. The result of this discussion was that the group became split with

Peter and John expressing uncertainty as to whether the rubber would conduct electricity whilst Sophie, Alice and Rachel all agreed that it would not.

When asked to design an approach for testing the materials the children propose the following (Table 39):

Time	Person	Verbal Report
23:59	Rachel	Keep the wires and everything the same just add the materials into the circuit one by one.
	John	I would get rid of the switch, cuz you won't really need the switch in there.

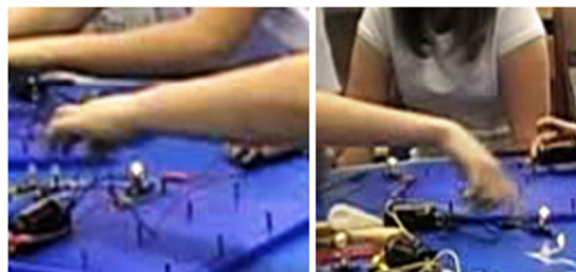
*Table 39: Rachel and John's ideas for how they can structure the test of materials in order to explore whether they conduct electricity.*

Once invited to carry out the testing the children adopted a scientific approach, they tested one item at a time and checked the results before placing all of the items that conducted electricity together and all of the items that did not together. When discussing the results of their testing none of the children expressed surprise and their discussions about metals conducting electricity was extended to include details based on the children's observations during the testing phase. Notably, John proposed that some metals when placed in the circuit resulted in the bulb shining brighter than it did for others and he suggested that when they tested the materials the piece of lead resulted in the brightest bulb.

Within this group there was some evidence of a change beginning to appear in the children's ideas about electricity in response to the conceptual challenge aspect of the activity. Whilst the overall framework of the children's ideas remained unaffected in their responses to what they thought electricity was at the end of the activity they now included the concept of energy. This term had not been used by the children previously during the activity and only emerged once the children have taken part in the electrons role play. The free responses provided by the children further supported the view that the children had been able to explore something new within this task, Rachel stated "*I don't think that I was like a 100% sure...but I thought it would all go at once...*" Sophie proposed that she hadn't known what to expect and Alice acknowledged that she already had the idea that the electricity would travel round the circuit (see transcript extract Table 40, Figure 36).

Time	Person	Verbal Report	Gesture
40:04	Sophie	I don't know, I didn't really know what to expect really.	
	Alice	I did, cuz I knew it would go round like, but I won't really like.	As she speaks Alice uses her right hand to draw a circle in the air in front of her.
	Rachel	I don't think that I was like a 100% sure, bits of electricity going through at a time, but I thought it would all go at once, I didn't think it would be bit by bit.	Points to the circuit in front of John.

*Table 40: Sophie, Alice and Rachel's responses to the conceptual challenge aspect of the task.*



*Figure 36: John's referential gesture (Table 38) and Alice's representational gesture (Table 40).*

The inclusion of the term energy begins to move the children towards an even more advance scientific model of electricity. Interestingly, no such inclusion was observed within any of the data from the younger children in Year 2.

Taken as a whole this particular group study begins to offer support for the conceptual challenge aspect of the task. The results appear to show the beginnings of conceptual change that would probably be associated with a form of weak restructuring (e.g. the children add new knowledge to their existing ideas but they do not change the core concept within these existing ideas radically). In addition, this particular group demonstrated the importance of understanding the social context of learning, these children frequently engaged in debate, questioned ideas that were presented by others and offered social support when peers were struggling to articulate their ideas.

#### **6.4.4 Year 9 Group Study**

The Year 9 group study focuses on a group of four children (two female, two male) called Janet, Alisa, Liam and Noel from Village Secondary School (see Storyboard 3, Figure 37). This group study lasted approximately 30 minutes. It should be noted that this was much shorter than the activities that had been held with the other children, in part because none of these children struggled with constructing the circuits and in part because this group quickly generated ideas, built on those ideas, and were then ready to move on. The activity was held in a vacant science laboratory within the school. Throughout the activity one secondary school science teacher remained in the room in order to observe and comply with the insurance specifications of teaching in this environment. The group was randomly generated by the researcher who formed the group by drawing names from the consent forms provided by the participating children. The researcher had no prior knowledge of the children's academic ability prior to forming the group but it was proposed by the class teacher that the children in this class were of mixed academic ability. This group of children worked well together but tended to be quieter than the younger children during the activities, they did discuss ideas and sometimes offered support to each other during the activity but this is no way close to the scale that is observed within the Year 6 group study.

At the beginning of the activity the children were probed for their ideas about electricity. All of the children agreed that electricity powers things and is a form of energy. When probed about their understanding of what type of energy this might be Janet proposed that she thought it was 'kinetic' energy and that this was 'a movement'. When probed for their knowledge of the symbols that were used for different electrical components, all of the children were able to name and identify the cell, bulb, wire, switch and motor. However, none of the children were able to identify the symbols for ammeter and voltmeter. As these children were familiar with the symbols for cell and bulb they were issued with that worksheet rather than the one with pictures. All four children's drawings revealed that they understood the need to draw in wires between the cell and the bulb. There were no additional inclusions made into these drawings. It is suggested that the drawings produced by these children revealed their underlying understanding of the need for a complete circuit in

order for the bulb to light. In addition, all of the drawings were completed using wires that connected to the poles of the battery. Notably, the children in this age group produced more rectilinear drawings than the drawings produced by the younger children.

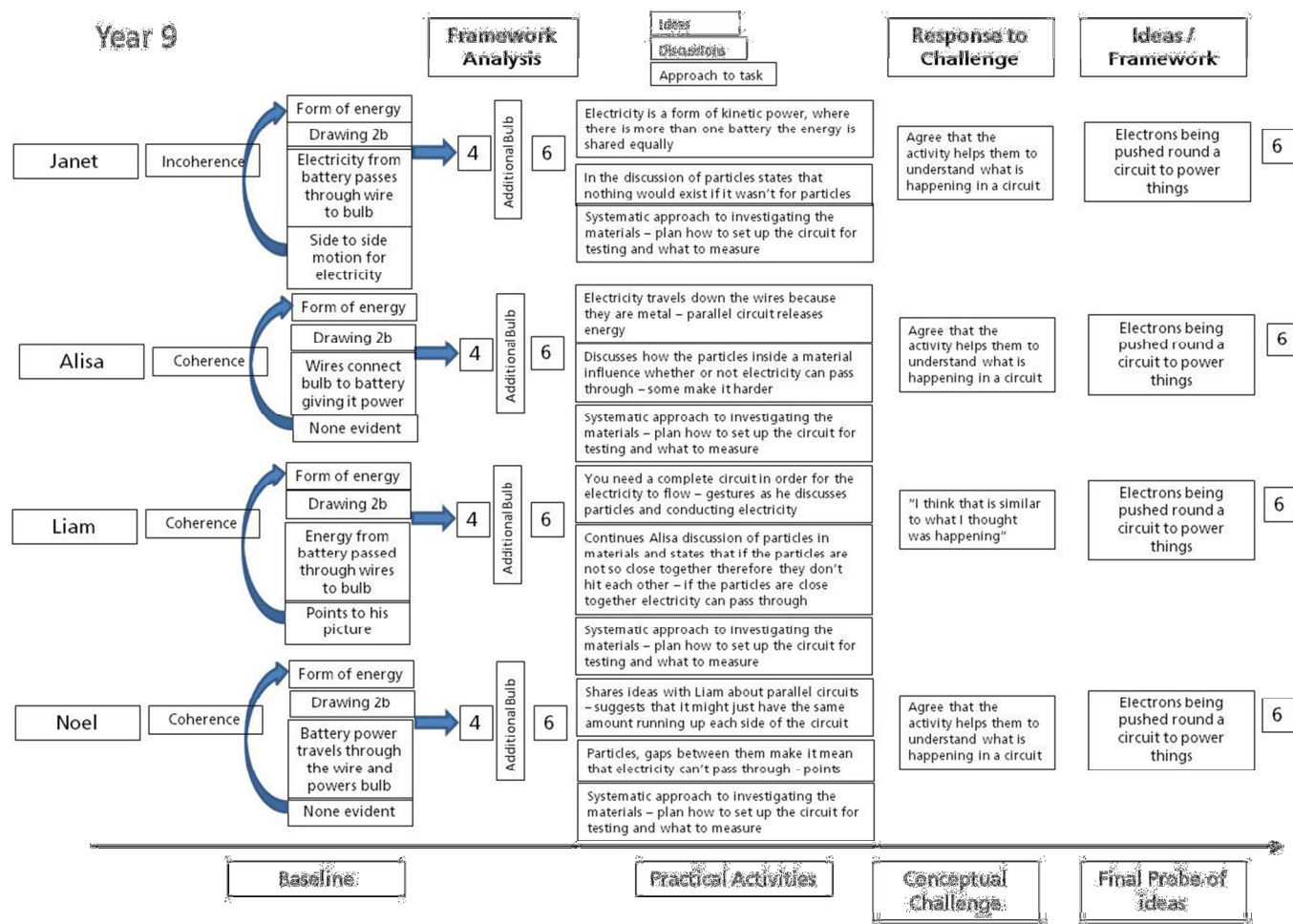


Figure 37: Storyboard from Year 9 electricity activities.

All four children provide written responses to the sentence completion task “*The bulb lights because...*” and these responses were as follows:

*Electricity from the battery passes through the wire to the bulb* (Janet)

*Wires connect the bulb to the battery giving it power* (Alisa)

*Energy is passed through the wires to the bulb* (Liam)

*Battery power travels through the wire and powers the bulb* (Noel)

The written responses further revealed the children’s understanding that the battery transfers its energy through the wires in the circuit in order to make the bulb light. It is important to note that other than Janet’s explanation of electricity being a form of kinetic energy none of the other children identified what kind of energy they thought electricity was. It is also notable that at this early stage in the activity only two gestures appeared to be produced, the first came as Janet explained what she meant by kinetic energy. As Janet discussed the movement of kinetic energy she used her right hand to make a side to side motion in the air in front of her (transcript extract Table 41). This representational gesture was used to show the way that she conceived kinetic energy (e.g. it is a movement through space).

Time	Person	Verbal Report	Gesture
01:20	Janet	Kinetic but that’s energy isn’t it, kinetic?	
	RS	When you say it’s kinetic what do you mean?	
	Janet	It a movement.	As she says movement Janet uses her right hand to make a side to side motion in the air in front of her.

*Table 41: Janet uses a representational gesture in order to show how she thinks kinetic energy moves (RS = researcher).*

The second occurrence of gesture appeared as Liam discussed his ideas for what he thought was happening inside a circuit. As he talked Liam used both a thinking gesture and a referential gesture, the initial thinking gesture (bouncing the pencil between which thumb and index finger) kept pace with his verbal response,



however, once he articulated the word light he then used a referential gesture in order to point to the bulb in his circuit diagram (transcript extract Table 42, Figure 38). This referential gesture helped to support his verbal articulation by adding further detail (e.g. his pointing gesture directs attention to the bulb on the page and allows Liam to anchor his discussion to this object).

Time	Person	Verbal Report	Gesture
03:27	RS	Okay, so can I ask you then, what do you think is actually happening in that circuit to make the bulb light?	
	Liam	The energy from the battery is being passed through the wires to the light which makes it light up.	As he speaks Liam bounces the pencil between his thumb and index finger, when he says light he indicates to the picture of the bulb on his paper and then continues to bounce the pencil again.

*Table 42: Liam uses two gestures to illustrate his ideas about why the bulb lights in his drawing (RS = researcher).*

The framework analysis conducted on the children's ideas revealed that all four children held a 'closed circuit' model for their ideas of electricity (Osborne, et al., 1991, Borges & Gilbert, 1999). The closed circuit model was allocated as at this point in the activity the children had demonstrated their understanding of the need for all circuit elements to have two connections. In addition, and at this point in time, it was clear that the children did not differentiate between current and energy.



*Figure 38: Liam's referential gesture (Table 42) and his referential and representational gestures (Table 43).*

However, once the task was changed and the children were probed for their ideas of what they thought would happen to the brightness of the bulbs once more were added to the simple circuit, all of the children appeared to apply a 'sharing' model for their ideas of electricity. Notably, the children proposed that two bulbs share the current in a circuit and the battery was perceived as a constant source of current. An example of this can be seen in Liam's response (transcript extract Table 43, Figure 38). Liam proposed that there would be the same amount of electricity in the circuit and this electricity had to power both bulbs, therefore the power had to be shared between them both. In addition, Liam supported this proposal with a referential gesture pointing to objects in order to anchor his verbal discussion to specific objects.

Time	Person	Verbal Report	Gesture
06:34	Liam	Because there is the same amount of electricity but it's got to power both bulbs and so you've got to share it between the two of them. Not as much energy goes to both bulbs.	As he speaks he points to the battery and then to the bulb and then lifts his hand up so that it is held flat with the palm upwards.

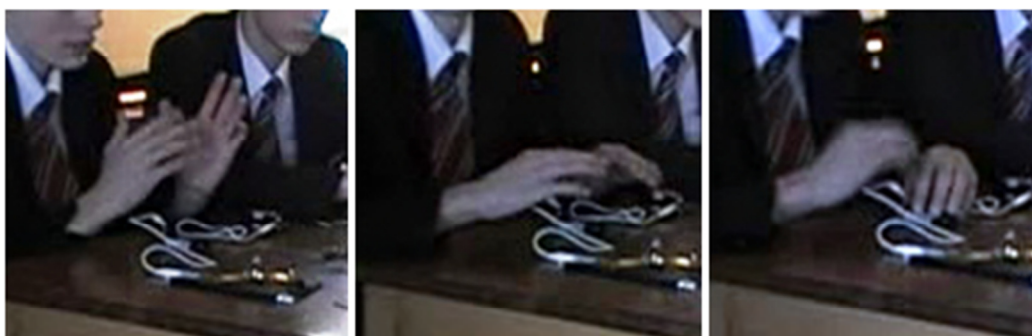
*Table 43: Year 9 child, Liam used a referential gesture in order to anchor his discussions to the objects.*

Overall, the gestures produced within this group were far less frequently occurring than they were within the groups of the younger children, however, gestures were used at some critical points within the activities. For example, when the children discussed their ideas about why different materials conduct electricity the children entered into a discussion about particles, their placement in different materials and the way that this influenced the materials ability to conduct electricity. These verbal discussions were accompanied by representational gestures that helped to demonstrate the potential movement of electricity through these materials. In the first example, Liam used his right hand in order to make a sideways motion. It is proposed that his hand represented the electricity and the sideways motion that he used his hand to make represented the movement of the electricity. Liam's discussion continued and he produced another representational gesture; this one was interpreted as being used to show how he thought the particles in the material touched each other. Liam's initial gesture which showed the sideways movement of the electricity was echoed later in Noel's discussion when he made the same sideways motion across the front of his body in order to represent the movement of the electricity through the material (see transcript extract Table 44, Figure 39).

Time	Person	Verbal Report	Gesture
12:04	RS	What is it about that material do you think?	
	Janet	I don't know.	
	Liam	Maybe it's the particles inside of it.	
	Alisa	They must be harder for it to travel through.	
	Liam	They must be harder for it to travel through...cuz they are not as close together so they can't hit each other as easily.	As he says this Liam raises his right hand and makes a sideways sweeping motion, he then puts his hand back down onto the top of the table... As he speaks he raises both of his hands from the top of the table, holds them vertically (fingers pointing upwards) and slowly draws his hands close together

			and then apart again.
	RS	Okay, you talked about particles there, what are particles? Or what do you think they are?	
	Liam	They are like erm, little, erm particles.	Laughs
	RS	Is everything made of particles?	
	Liam	Yeah.	
12:45	RS	And can you see them?	
	Liam	No.	
	RS	So how do you know that they are there?	
	Janet	Cuz if they wasn't there wouldn't be anything cuz particles are what makes an object.	
	RS	You also talked about particles not being so close together, why might that be important for whether or not electricity passes through?	
	Liam	If they are close together it's easier to pass through.	
	Noel	If there is like a gap then they can't get through.	As he speaks Noel uses his right hand to make a slight sideways movement in front of his body.

*Table 44: Transcript extract showing how the Year 9 children use gestures in order to support their discussions of why conductivity occurs (RS = researcher).*



*Figure 39: Liam's representational gestures (Table 44).*

This particular discussion marked a critical moment within the activity where all of the children began to pull their ideas together and contributed to the generation of a more advanced concept. The discussion which focused on the placement of particles

in materials also offered insight into how these children work together in order to support the development and articulation of ideas. Janet initially proposed that she did not know why some materials were able to conduct electricity whilst others were not. However, Liam offered the argument that it was because of the particles inside the material and Alisa added to Liam's ideas by suggesting that it made it harder for the electricity to pass through. Discussions such as these demonstrated how it was possible for the children to build on ideas and produce progressively more advanced explanations for scientific phenomena. What was clear from this extract was that none of the children disagreed with Liam's proposal instead they supported his ideas and offered additional information to take his discussion further, in fact by the end of the extract all four children had contributed to this discussion equally.

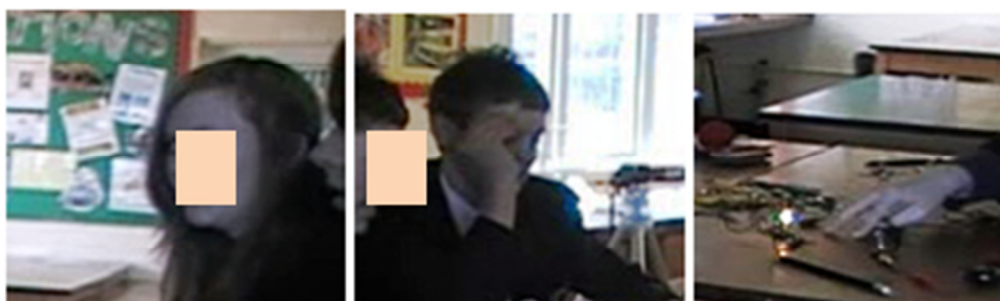
As the activity moved on the children demonstrated a high level of accuracy for sorting the materials according to whether or not they would conduct electricity or not, in this instance only one item is incorrectly proposed to conduct electricity. When the children are asked why they had decided to sort the materials in this way Janet proposed that the conductors were chosen because "they are metal". Alisa confirmed this and stated that metal should work because it was like the wires and they conducted. When probed about why the plastic, rubber and wooden items had been placed on the insulator pile Liam responded by saying that he remembered from primary school. When asked to design an approach to testing the materials as a group, the children decided that they needed to keep the same circuit for all materials, that this circuit would contain one battery, one bulb and three wires, all of which would have been tested before beginning to try the materials and that they would observe the brightness of the bulb. The group adopted a scientific approach to testing the materials; they tried one item at a time and observed whether or not the bulb lit. Once tested, the children placed the items into new piles which had been allocated as conductors or insulators.

Another significant moment within this group activity occurred as the researcher discussed parallel circuits. At first the children were unsure of what this was or what it meant. Evidence for this view can be drawn from the transcript extract (Table 45, Figure 40) in which it was possible to observe both Janet and Liam stating 'no'. These two children did appear to share some non-verbal interaction. Noel stated that he thought that they have done one and his gesture appeared to support this view.

Running his fingers across his eyebrow is resonant with typical thinking gestures that had already occurred during this study. The researcher demonstrated the circuit and then asked the children to predict what would happen to the bulbs if an additional one was added. As they did for the series circuit, all of the children predicted that the electricity would have to be shared between the bulbs and that they would appear dimmer.

Time	Person	Verbal Report	Gesture	Other Non-verbal
17:45	RS	Do you know what a parallel circuit is?		
	Janet	No.		Janet rolls her eyes, and then smiles all of the others look towards her.
	Liam	No.		Liam looks down at the table and smiles.
	Noel	I think we have done one.	Noel pulls his right hand up to the side of his face and runs his fingers across his eyebrow.	

*Table 45: Year 9 transcript extract showing group sharing gestures during their discussion of parallel circuits (RS = researcher).*



*Figure 40: Janet and Noel's social gestures (Table 45) and Alisa's referential gesture (Table 46).*

Once these predictions were elicited from the group the children were invited to add another bulb in parallel and then explain the results. The children's ideas were captured in the transcript extract (Table 46). This extract provided evidence of how this group of children progressively built on the concepts introduced during this discussion in order to generate a more complex framework of ideas.

Time	Person	Verbal Report	Gesture
19:22	Alisa	Cuz the powers still being released.	Alisa points to the circuit in front of her.
	Janet	Cuz it's like...	
	Noel	I don't know.	
	Janet	The electricity is being, the same amount of electricity is being used, it's just going up and down and they are all getting the same amount because they are connected to each other kind of.	As she speaks Janet first points to the circuit and then uses her left hand to make a up and down motion that runs the length of the circuit as she stops speaking she looks at the RS and smiles.

*Table 46: Transcript extract from Year 9 group discussing their ideas about a parallel circuit.*

Finally, in this particular group study there was strong evidence of a change in ideas resulting from the conceptual challenge aspect of the task. With this group of children, their ideas for what electricity was were revised from it being a "form of energy" to it being "electrons pushed round a circuit to power things". The overall frameworks for electricity understanding did not appear to change but the children did incorporate new information that appeared to play a central role to their understanding of what electricity was. Notably at the beginning of the science activity the children were aware that electricity was a form of energy that powers things but what form this energy took was undefined. By the end of the activity the children all appeared to be incorporating an awareness of electrons into their ideas thus providing a definition for what the characteristics of the form of energy involved.

When probed for whether they thought that the use of the smarties to represent electrons had been different to their existing ideas, Liam proposed that it was indeed

similar, but all of the children agreed that the demonstration had helped them to understand what was happening in a circuit. It was this acknowledgement that may have helped the children to use the information drawn from the analogy in order to further develop their own ideas (transcript extract Table 47).

Time	Person	Verbal Report	Gesture	Other Non-verbal
24:00	RS	Okay so is that similar to what you thought might be happening within the circuit or is it different?		
	Liam	I would say it is similar to what I thought was happening.	Liam nods his head.	
	RS	Yeah, do you all agree?		The children all nod.
	RS	Does that help you to understand what is happening in that circuit?		
	Noel	Yeah.		The others nod their heads.

*Table 47: Transcript extract from Year 9 showing the group's response to the conceptual challenge aspect of the activity (RS = researcher).*

In terms of the success of the approach taken within this study which explicitly aimed to challenge children's ideas in order to observe how they may begin to change once challenged this particular group study was particularly useful. The results demonstrated the effectiveness of the conceptual challenge aspect of the task and the information from this group was used in order to conduct a more thorough timeline analysis exploring the development of conceptual ideas about electricity over the course of the activity (see section 6.5 for further details).

## 6.5 Mapping Conceptual Change across an Activity

In order to explore in more detail the way that the children's ideas changed within the context of the practical science activities a timeline analysis was conducted on the Year 9 group study data. The timeline analysis was developed from the work of Givry and Tiberghien (2012) as discussed in Chapter 5. The aim of this analysis was to



map each new concept that the children discussed across the course of the activity in order to pinpoint moments of change as they happened. The Year 9 group were selected as they showed clear evidence of a change in concepts between the beginning and the end of the science activity, notably this group revised their ideas about what electricity was from a “*form of energy*” to “*electrons being pushed around a circuit to power things*”. This group also has a number of interesting interactions and showed evidence of generating new ideas between them.

The timeline analysis detailed in Figure 41 shows the new ideas that were presented by the children during the activity. In order to show how these ideas developed over time the concepts are linked to the initial child who proposed them and the timeline across the bottom shows when these new ideas appeared. When initially probed for their ideas the timeline shows that Janet initially discussed electricity in terms of power. The children discussed how electricity powers things including light bulbs, when probed for what kind of power electricity is Janet linked the idea of power to the additional concept of energy. This link between these two ideas was continued until around two minutes into the activity when the children had completed their diagrams and were asked to provide an overview of what they thought was happening in the circuit in order to make the bulb light. It was at this point that Liam introduced the notion that energy is passed through the wires to make the light from the bulb. This idea was further developed by Alisa who introduced the new concept of conduction in order to explain the process of electricity being passed through the wires. Subsequently, Noel added to this conceptual map by proposing that electricity was also passed back to the battery. In this 7 minute interval it is possible to see how the children move from a conceptual structure which contains one idea, to a two idea structure, then a three which contains the exclusion of one concept and the introduction of two new ideas. This is subsequently altered to a two concept structure which introduces a new principle that aims to explain the phenomena initially proposed and then a further three concept structure which extend these ideas further.

The next time window, 11 – 17 minutes into the activity, captures the ideas that are produced when the children begin to consider the concept of conductivity in more depth. It is at this point in the activity that Liam builds on previous ideas about electricity in order to produce a more complex four concept for conduction. As can be

observed in the timeline diagram, Liam links the ideas of energy and its ability to pass through materials to the concept of the underlying particle arrangement within the material. He proposes that it is the distance between the particles that the material is made of that influence whether or not something will conduct the energy. It is at this point that the first network of four ideas is produced and this begins to reveal the complexity of the conceptual structure that these children have for electricity. The network of four ideas is partially revised by Noel who discusses the particles arrangement found in different materials in terms of both conduction (when the particles are close together) and insulation (when the particles are far apart).

The children all appear to support and apply this network of four ideas throughout the next part of the activity and revisions are only made once the children move into the 17 – 24 minute stage of the activity. Here there is further evidence from Liam that he is still developing the way that he views the movement of electricity, notably he now can be seen to link the energy that he associates with electricity and a ‘flow’ movement. The introduction of the term flow appears to reveal more about the way that he thinks the electricity moves, whilst previously he has talked in terms of passing the idea of flow can be interpreted as being something distinctly different, e.g. when water flows it moves as a body which is generally pushed by some force, whilst passing can be an isolated movement of an object which is propelled by some internal forces as well as a pushing force from behind. It is suggested that perhaps the most interesting changes in the children’s conceptual structure appear once their ideas have been challenged using the smarties analogy. Here the children are encouraged to act out the role of the electrons in a circuit; they carry the smarties (which are used to represent the energy that is generated within the battery) around the circuit. The researcher encourages the children to think in terms of being pushed as there are additional electrons which are being pushed out the battery and in turn move them forward. Once this activity is complete the children are told the story of Volta and his invention of the first battery, this is used for two reasons, firstly it helped to add further context to the activity, and secondly, this allows space between the researcher’s presentation of the analogy and the final probe of science ideas. In this particular group of children by the 25 minute timescale it is possible to observe Liam generate a new and previously unused network of three ideas in his final definition of what he thinks electricity is.

Liam links the idea of electrons, a concept that the children had not previously used at all during the activity, with the ideas of being pushed around a circuit. It is interesting to note that this network of three ideas appears to contain the notion that the movement of the electrons is heavily influenced by other factors in the circuit and the introduction of the term circuit acknowledges the importance of the connection between the wires and the bulb and the way that this system operates as a whole.

Whilst it is not possible to comment on whether this new network of three ideas remains consistent over time, within this context of this particular activity the appearance of this new network of ideas appears to show evidence of a radical form of conceptual change whereby the central concept is altered from that of power / energy (as shown in the timeline at 0 – 2 minutes) to electrons being pushed around a circuit (as shown at 25 minutes in the timeline). Results such as these were strongest within the Year 6 and Year 9 groups. Interestingly although the Year 2 children participated in exactly the same activities they did not incorporate any of the new ideas presented into their subsequent discussions of what they thought electricity. Evidence of change was, however, was evident with the Year 6 and Year 9 groups, with changes appearing to occur at both a weak and radical level.

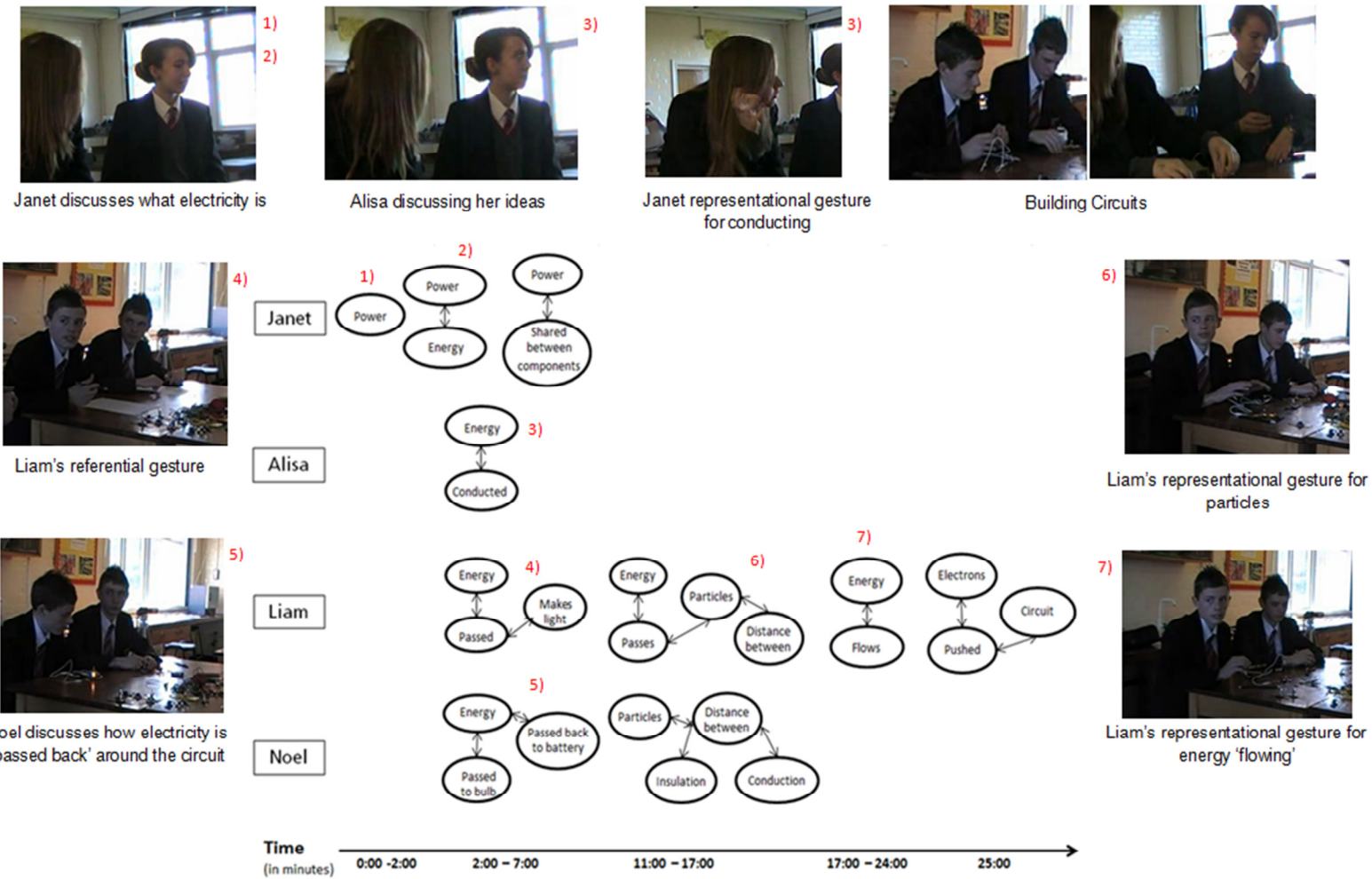


Figure 41: Timeline analysis for the Year 9 group data.

## 6.6 Discussion

The results of the multimodal analyses of data from the three groups support the notion that a multimodal approach can be used effectively in order to explore children's ideas about electricity. The results also revealed that additional information on the children's ideas can be gained from the analysis of gesture and that these gestures do reveal important information about ideas that is not transmitted in speech or written language or other mean (e.g. drawings).

Further to this, evidence from a Year 6 group demonstrates the importance of adopting the multimodal approach to understanding children's ideas more fully. One critical analysis of the Year 6 children's responses to the electricity tasks revealed that children did not necessarily apply their frameworks for electricity consistently across all of their responses and many children changed the framework that they used when they were asked to pass comment on what would happen if an additional bulb were added to the circuit and why they thought this would happen. In a minority of cases the children used less scientific models in their responses to the more complex questions and tasks. In other cases the children used more complex and scientific explanations. It was the following case study that highlighted this inconsistency between the applications of models depending on the context of the question.

Daniel was a Year 6 participant, he played a very active and vocal role in the group activity and readily shared his ideas. He also frequently used gestures alongside his verbal responses. Daniel's gestures were particularly revealing as they showed that he applied two different frameworks for his understanding of electricity depending on the number of bulbs that were to be included in the circuit. In the transcript extract below (Table 48), Daniel applied the closed circuit model in both his verbal and non-verbal responses. Daniel's gesture demonstrated a slow movement around the circuit in a circular motion (Figure 42). This particular gesture was typical of the non-verbal approach to demonstrating how electricity moves around a circuit in one direction from battery to bulb and then back to the battery. In his verbal response Daniel stated that electricity passed through the wires and in turn through the different metal components in the circuit. His verbal responses were supported by

his non-verbal gesture. Another participant, Chris, uses a similar non-verbal gesture to also demonstrate this understanding of how electricity moves in the circuit.

Time	Person	Verbal Response	Gesture	Other Non-Verbal
	Daniel	The electricity is passing through the wires to the metal and electricity passes through metal which is travelling through more metal which is travelling through more metal	As he speaks Daniel uses his right hand to make a slow movement which traces the wires around the circuit that his group has made	
	RS	Does the electricity stay in the bulb or does it go somewhere else?		
	Chris	It keep on going round and round	As he says this Chris uses the index finger of his right hand to draw a continuous circle above the circuit that his group have made. As he completes this sentence his gesture stops	
	RS	Okay. What would happen if I was to put another bulb in that circuit?		
	Isabelle	Oh it wouldn't be as bright...would you need two batteries...no		
	Daniel	If...no wouldn't you be fine because would electricity pass through each side of the battery	As he says this Daniel places both of his hands either side of the battery and then slowly draws a path with each hand that follows the wires on either side of the circuit that his group have previously made and stops when they reach either	As he is talking Daniel scrunches up his forehead and looks puzzled

			side of the bulb in the circuit	
	RS	Well what do you think? Do you think it will pass through each side?		
	Daniel	I think it will		
	Tony	That will just get duller cuz they will share the electricity	Tony uses his left index finger to point to the bulb as he speaks	
	RS	Does that always happen then? That if you put more bulbs into a circuit that they share the electricity that is already there?		
	Daniel	Yeah		As Daniel speaks he scrunches up his face looking puzzled

*Table 48: Extract of the transcript from a Year 6 group electricity activity which shows Daniel applying two different frameworks of understanding once the context of the activity is changed.*

However, once the researcher asked the group what would happen in the circuit if an additional bulb was added Daniel changed the framework that he used to describe his understanding of electricity. The change occurred in both Daniel's verbal and non-verbal responses, he proposed that the electricity would travel from each side of the battery, one side per bulb. A similar representation is observed in his non-verbal response, he drew two path gestures which began at the bulb, notably each hand traces a separate wire towards the existing bulb in the circuit (Figure 42). This verbal response and gesture is typical of a response that demonstrated a clashing currents model for electricity. In this instance it is proposed that Daniel's understanding appeared to regress to a less scientific model than he had demonstrated before as a result of the task characteristics or context specificity elucidated during this probe. There is also evidence in Daniel's other non-verbal behaviour that he is confused by this new aspect to the task (e.g. he scrunches up his face and appears puzzled).



*Figure 42: Daniel and Chris' representational gestures showing his ideas for how electricity works in a circuit.*

The timeline analysis adopted and developed during this work revealed itself to be useful for highlighting moments of change as they occurred. Interestingly, the Year 9 children showed most evidence of conceptual change during the electricity activities and the timeline effectively captured these. This showed how the children moved from a single idea conception of what electricity is to a more advance three-concept idea.

Overall, the results of the analyses revealed that, consistent with previous literature, the older children demonstrated most scientific and advanced concepts (Shipstone, 1985; Osborne, et al., 1991; Borges & Gilbert, 1999). The older children were also more likely to change their ideas following tuition. However, the changes evident were not necessarily at framework level and often took the form of weak restructuring. There was some support for Karmiloff-Smith's (1992) ideas of conceptual change found within the data (see Chapters 3 and 8).



## **Chapter 7 Children's Ideas about Floating and Sinking (the Archimedes Principle): a multimodal perspective**

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### **7.1 Introduction**

In this chapter the analysis of, and findings from, the floating and sinking activities are presented and discussed. The results are structured according to both 'conventional' approaches to studying children's ideas and the new multimodal, task-based approach in order to investigate what this approach adds to an understanding of the children's ideas and how these change as a result of tuition.

In the first part of the chapter, the analyses explore the content of the children's drawings and written and verbal responses during interview. These are analysed using a 'conventional' approach. In all cases, content analyses were undertaken on the children's individual worksheets (as discussed in Chapter 4) and the group transcripts drawn from the floating and sinking practical activities. These permitted examination of the underlying frameworks of understanding that the children were using when discussing their ideas and structured around:

- what floating is;
- what sinking is;
- what kind of objects float and sink and their properties.

In the second part of this chapter, different aspects of the multimodal analyses are presented. Following transcription, the data were coded using NVivo in order to complete the multimodal analysis. NVivo offered a particularly powerful platform for this analysis by drawing together the transcripts from multiple cases and making it possible to trace coding across and within transcripts as discussed in Chapter 5. This more detailed level of analysis permitted the identification of the different types of gestures that children used as well as indicating the prevalence of these across the three age groups. In order to explore the utility of the storyboarding approach

detailed in Chapter 5, three group studies were conducted. Each group study was transcribed in full and the comparative analysis between the different response types was completed by hand. These storyboard analyses explored the ways that the children used different response types (e.g. drawings, written, verbal and gestures) in order to show their understanding during the activities and the way that the children's ideas changed (if at all) during the course of the activities. Finally, in order to show how ideas developed during a single activity a timeline analysis was completed for one of the Year 6 groups, this group was chosen because their ideas appeared to have changed and they frequently used collaboration to generate new ideas as the activities progressed. This groups' data were transcribed fully and coded by hand in order to capture the transition between the concepts that children were discussing during the activities. Finally in this chapter, the results to the activities are compared to previous research and the importance of studying gesture is assessed using the data collected during Research Phase 2.

As highlighted in Chapter 3, floating and sinking has historically been studied less than electricity. Although less well studied in the research literature, floating and sinking is embedded within the National Curriculum for Key Stages 1- 4 in Materials and their Properties it also overlaps with Physical Processes at Key Stage 3 and above (DfEE & QCA, 1999). According to the guidance:

- Key Stage 1 – pupils are taught to be able to sort materials into groups on the basis of properties including the ability to float;
- Key Stage 2 – pupils are taught to compare objects and also receive tuition in physical processes such as gravity;
- Key Stage 3 – pupils are taught about density, the particle theory of matter and about balanced forces;
- Key Stage 4 – pupils are taught about the atomic structure of materials and receive further tuition on forces.

As with electricity, children's learning is measured in National Curriculum terms according to Attainment Targets which consist of 8 level descriptors of increasing difficulty, plus a description of what exceptional performance would be. The

attainment levels for each topic are available from the Department for Education. According to the DfEE and QCA (1999) children are expected to attain the following levels at the following ages (Table 49):

Range of levels within which the great majority of pupils are expected to work		Expected attainment for the majority of pupils at the end of the Key Stage	
<b>Key Stage 1</b>	1-3	<b>At age 7</b>	2
<b>Key Stage 2</b>	2-5	<b>At age 11</b>	4
<b>Key Stage 3</b>	3-7	<b>At age 14</b>	5/6
<b>Key Stage 4</b>	National qualifications are the means of assessing attainment		

*Table 49: The range of levels children are expected to work within and the expected attainment for the majority of pupils at the end of the key stages.*

The presence of floating and sinking specifically in the primary curriculum highlights that all of the children involved in this study will have received some form of tuition prior to undertaking the activities. However, for the older children it may have been some time since they had worked directly with such materials.

## 7.2 Traditional Approach to Analysing Children's Ideas

As detailed in Chapter 4, the following participants were recruited for the floating and sinking activities undertaken as part of Research Phase 2:

- 19 children in Year 2 at Village Primary School;
- 16 children in Year 2 at City Independent School;
- 28 children in Year 6 at Village Primary School;
- 16 children in Year 6 at City Independent School;
- 14 children in Year 9 at Village Secondary School.

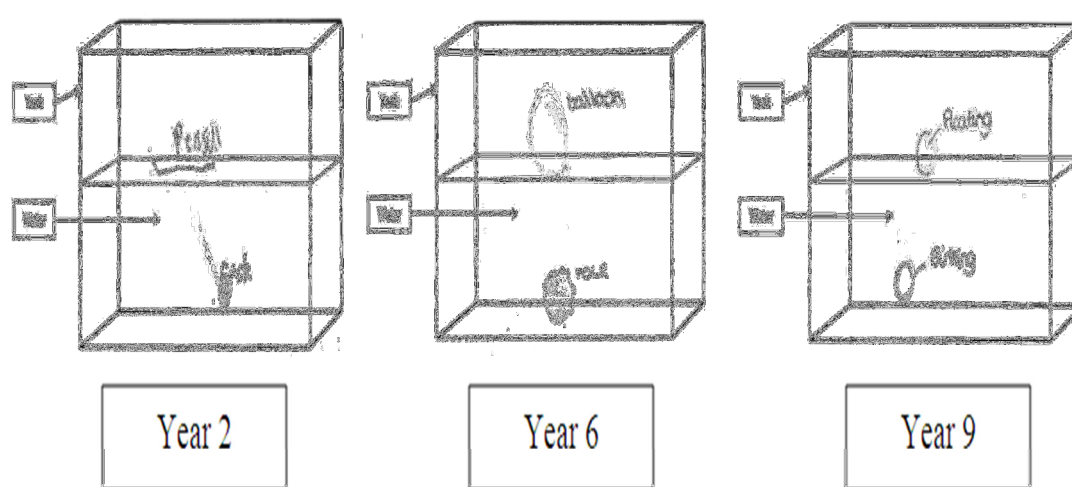
The children completed the floating and sinking activities as detailed in Chapter 4, section 4.6. In summary these activities entailed the children first taking part in a

baseline test for their ideas about floating and sinking. This included a discussion of what they thought floating and sinking was, and drawing and sentence completion tasks. These tasks were followed with a problem solving activity where the children were asked to group materials (including cork, plastic, metals such as copper and steel and different types of wood) according to whether or not they thought that they would float or sink, develop an effective means of testing the materials and then discuss their results. Next the children were asked if they could mould plasticine in order to make it float, including when loaded with marbles. Children's existing ideas were then challenged by pushing an inflated balloon into a tank of water so that they were able to observe the change in water level as the balloon displaced the water and feel the upthrust force on the balloon itself. Finally, the story of Archimedes' discovery of how to explore the density of objects using water was discussed before the children took part in a final probe of their ideas. The researcher led all activities and was responsible for delivering the dialogic teaching. Throughout the activities the researcher used a participant observation approach in order to judge when the appropriate time to ask specific questions was and in order to assess when the activities should be moved on.

In order to explore children's ideas in floating and sinking, a content analysis was conducted on the transcripts drawn from the floating and sinking practical activities. The analysis undertaken considered the content of the children's drawings, written and verbal responses in order to uncover the underlying frameworks of understanding that the children had been using when discussing their ideas for why objects float and what characteristics objects require in order to be able to do this. In order to explore the way that the children's ideas changed between the three age groups of children, a comparison of the features of children's drawings was undertaken. This was followed by an analysis of the content of their written work and an analysis of the content of their verbal responses using the same comparative approach.

### 7.2.1 Children's Drawings

A qualitative content analysis of the children's drawings was completed in order to explore how these changed over time. In most cases, although there were exceptions, the drawings contained only two objects. Typically across all age groups one object was drawn above or directly touching the water surface and one was drawn at the base of the tank usually touching the bottom (Figure 43 shows typical examples from the three age groups).



*Figure 43: The placement and type of objects that the three different age groups of children drew before completing the floating and sinking activity.*

The range of objects that were drawn varied but there were some emerging themes. Floating objects included boats, ducks, balloons and people, whilst sinking objects included bricks, blocks and rocks. Interestingly as the age of the children increased the drawings were more likely to contain identical objects in both the floating and sinking positions, perhaps indicating that as children get older they become more aware that the surface characteristics of the object (e.g. what they look like from the outside) cannot always be used to decide whether an object will float or sink (Figure 43).

In order to facilitate an analysis of variation across age groups regarding the placement of objects the distribution scores across each age group is presented in

Table 50. As demonstrated in Table 50 the location of the floating object was most frequently placed on the top of the water with none of the Year 9 participants placing the floating object above the water surface. Interestingly, no participants drew the floating object under the surface of the water, perhaps indicating that when children are considering floating objects they prefer those which sit at the top of the water. However, when the children were probed as to whether floating objects could appear in other locations all of the children agreed that it was possible for some objects to float in the middle of the water (e.g. completely submerged beneath the surface but not touching the bottom). Importantly, these results may be subject to context effects and perhaps if the children had been specifically asked about submarines they may have considered or provided different responses.

<b>Location of Floating Object (s)</b>		
<b>Age</b>	On top of water surface	Above the water surface
<b>Year 2</b> (N = 35)	N = 28 (80%)	N = 7 (20%)
<b>Year 6</b> (N = 44)	N = 38 (86%)	N = 6 (14%)
<b>Year 9</b> (N = 14)	N = 14 (100%)	N = 0 (0%)
<b>Location of Sinking Object (s)</b>		
<b>Age</b>	On the base of the tank	Above the base of the tank
<b>Year 2</b> (N = 35)	N = 13 (37%)	N = 21 (60%)
<b>Year 6</b> (N = 44)	N = 31 (70%)	N = 13 (30%)
<b>Year 9</b> (N = 14)	N = 11 (79%)	N = 3 (21%)

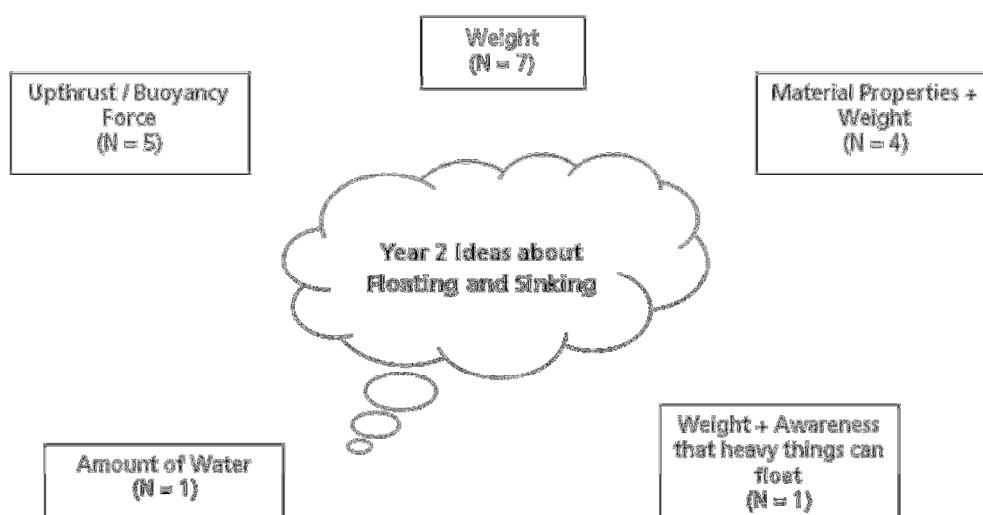
*Table 50: The distribution of the different locations for the floating and sinking objects produced by the different age groups of children in the study. (\* Some Year 2 children did not include a sinking object in their drawings.)*

The results of the drawing location of the sinking object revealed less consistent results. The youngest children most frequently drew the sinking object above the base of the tank (N=21; 60%), however, in the older children both Years 6 and 9 the location of the sinking object was most frequently placed touching the base of the tank. Overall the results revealed a clear distinction between the two terms (e.g. floating was represented at the surface of the water whilst sinking was located at the

bottom). The results also revealed some age related changes with older children drawing objects that were less distinguishable in both floating and sinking positions.

### 7.2.2 Children's Written Responses

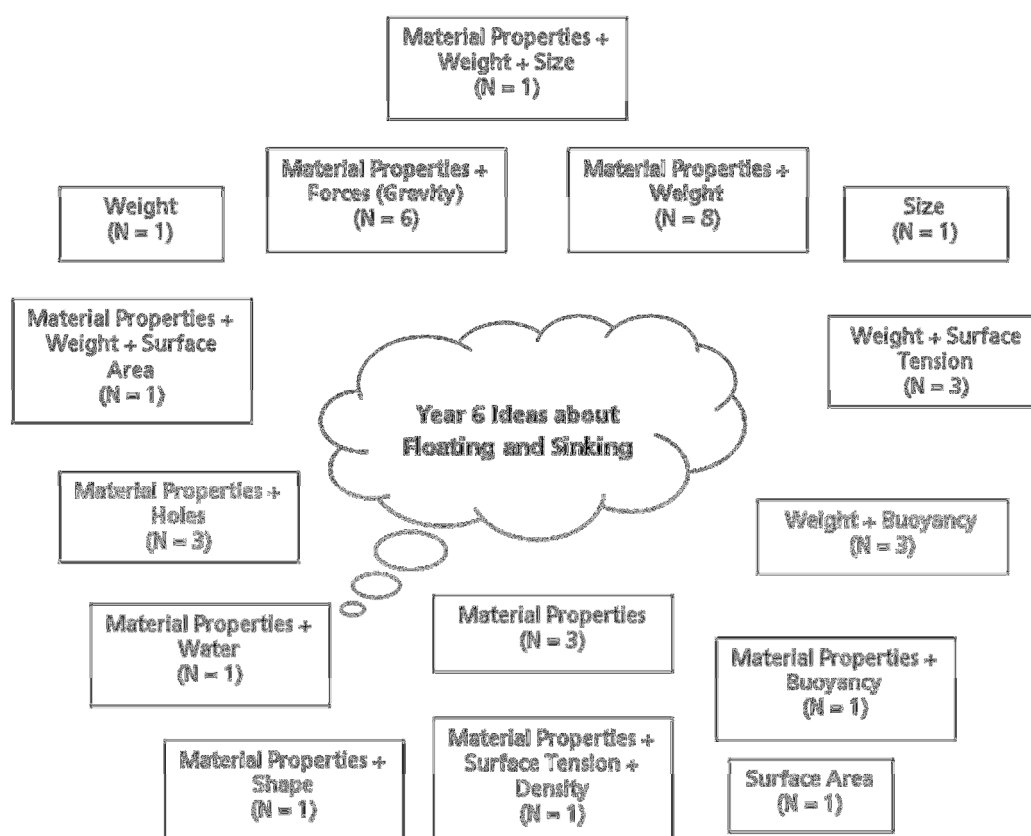
Qualitative content analyses of the written responses generated by the children across the different age groups revealed striking differences in the type of reasons given for why things float or sink. Notably, younger Year 2 children (7 years) frequently did not complete the written task at all (N=16; 46%). Of those that did the majority discussed weight as a factor. A total of five different explanations for why things float and sink were evident within this group (see Figure 44).



*Figure 44: The different written explanations that Year 2 children (7 years of age) give for why things float or sink.*

In terms of the ideas discussed it is proposed that discussions of weight represented the most intuitive idea that the children held and also the most concrete. In contrast some children presented more advanced scientific ideas including in their discussions the notions of upthrust and buoyancy, these ideas can also be considered to be more abstract.

In contrast, children in Year 6 (10 and 11 years of age) more frequently provided a written response to the questions with only 6 children (14%) failing to provide a written answer. Responses at this age included a wider range of variability than those provided by the Year 2 children. Some children still discussed the weight of the object as a critical factor whilst other explanations included size, the presence of holes in the material, whether the object is airtight, the ability to balance on the water and gravity (see Figure 45 for further details).



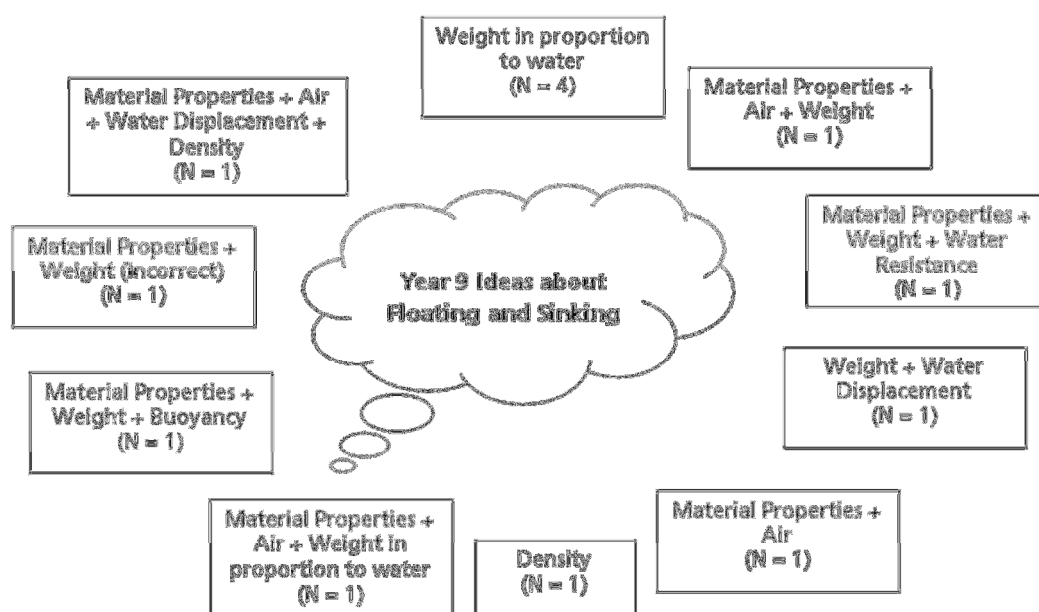
*Figure 45: The different written explanations that Year 6 children (11 years of age) give for why objects float or sink.*

As with the younger children, the Year 6 children included both intuitive and scientific ideas as well as those that were concrete and abstract. Intuitive ideas still included aspects linked to the weight of the objects and in concrete terms children discussed the presence of holes as one important factor. In contrast some Year 6 children included a discussion of forces in their written responses, such concepts are more



scientific and abstract in form. Interestingly, none of the Year 6 children discussed ideas such as upthrust and buoyancy.

The children in Year 9 (14 years of age) all provided written responses. These responses demonstrated extensive variability with some children still indicating that the weight of the object was important for whether things float or sink. However, at this age it was noted that children's ideas appeared to shift from an object-centred frame to one which included both the characteristics of the object and the characteristics of the liquid in which the object was placed, thus demonstrating more advanced scientific concepts. Explanations provided included factors such as water displacement, density of the object, the object's weight in comparison to the liquid, and the object's ability to be 'lifted' by the water based on its weight (Figure 46).



*Figure 46: The different written explanations for floating and sinking that were generated by Year 9 children (14 years of age).*

As with the younger children there was still some presence of intuitive and concrete concepts such as air in objects being a factor which is important for helping items to float. In contrast, scientific concepts included the weight of the object in proportion to

the water and the most abstract concept included a range of ideas such as the presence of air in the objects, water displacement and the density of the object.

Taken as a whole the ideas that were provided in the written responses to the worksheets demonstrated an interesting pattern of responses. Initially, the younger children appeared to produce just five different themes within their written responses. However, as children got older more variation in the written responses appeared; with the Year 6 children producing 15 different themes and the Year 9 children producing 10. It is interesting to note that whilst the weight of the object was the most popular theme emerging from the analysis of the youngest children's written ideas, this theme became combined with other explanations in the older children and its occurrence reduced substantially across the older groups. For example, the Year 6 children discussed the material properties of the objects (e.g. the thickness of the material or the presence of air as well as their weight).

### **7.2.3 Children's Verbal Responses**

Throughout the activities presented all of the children responded to a range of verbal probes designed to uncover their ideas about floating and sinking. These probes included:

- What do you think floating is?
- What do you think sinking is?
- What kind of things float?
- Why do you think these things float?
- What kind of things sink?
- Why do you think these things sink?

An initial analysis comparing the themes that emerged for what the children thought about floating and sinking was undertaken. The results of this analysis are shown below in Tables 51 and 52. The results for floating revealed that the youngest age group (Year 2) most frequently associated floating with the position of the object in

the water. The Year 6 children also often discussed the position of the object but also suggested that weight was a factor and that they thought floating might have something to do with forces. However, when probed they were unsure of what these forces were. Some Year 9 children still referred to the position of the object in the water but others did suggest that they thought that floating occurred when an object displaced more water than its weight. As with the written responses the data presented in Table 51 appears to show that in the youngest children only a few themes occurred, as the age of the children increases more ideas are evident, the number reduced again in the older children. It is proposed that the youngest children (Year 2) demonstrate the most intuitive and concrete ideas by attending merely to the actual location of the object in the water. The older children (Year 9) appeared to use the most abstract and scientific ideas and stated that floating was when an object displaced more water than its weight.

Intuitive ----- → Scientific	What is meant by floating?	Year 2 (N = 35)	Year 6 (N = 44)	Year 9 (N = 14)
	Is not sinking			2 (14%)
	Staying up	3 (9%)	4 (9%)	
	Things that go above the water surface		5 (11%)	6 (43%)
	Staying at the top of the water	12 (34%)	5 (11%)	
	Things sitting at the surface of the water (but not always)		16 (36%)	
	Staying at the top or sometimes in the middle of the water	20 (57%)	4 (9%)	
	When light things stay at the top		5 (11%)	
	To do with forces		5 (11%)	
	If something doesn't go under the water			3 (21%)
	Is something displacing more water than its weight			3 (21%)

*Table 51: A theme analysis of the children's responses to what they thought floating was at the beginning of the activity.*

The emerging themes in the children's verbal responses for what they thought sinking was revealed that the younger children (Year 2) most frequently associated this with the downward motion of an object through the water. In Year 6, many

children also discussed the motion of the object but others discussed the role that gravity played. Some of the Year 9 children discussed the downward motion but they also incorporated discussions of the weight of objects and the ability of an object to displace water (Table 52). It is proposed that the content of these verbal responses reveals a pattern of concept development which demonstrates that the youngest children apply the most intuitive and concrete ideas whilst the older children apply the most scientific.

Intuitive ----- → Scientific	What is meant by sinking?	Year 2 (N = 35)	Year 6 (N = 44)	Year 9 (N = 14)
	Going down slowly	3 (9%)		
	Things that go completely under the water		5 (11%)	
	When an object goes straight to the bottom	4 (11%)		7 (50%)
	Movement through the water to the bottom	28 (80%)	25 (57%)	2 (14%)
	When objects are heavy so they go to the bottom		5 (11%)	2 (14%)
	Gravity making heavy objects sink		5 (11%)	
	Falling or being pulled by gravity		4 (9%)	
	When an object cannot displace enough water equal to its weight			3 (21%)

*Table 52: A theme analysis of the children's responses to what they thought sinking was at the beginning of the activities.*

In order to further reduce the vast quantity of verbal data so that meaningful comparisons could be made across the age groups it was necessary to develop a framework system for the different ideas that children demonstrated.

#### **7.2.4 The Development of a Framework System about Floating and Sinking**

In order to further analyse children's ideas about floating and sinking, a framework structure of children's responses informed by recent research by Havu-Nuutinen (2005, see Chapter 3) and further developed through the content analysis of the written and verbal responses made by the participants in the current study (see Table 53). It is important to note here that whilst Havu-Nuutinen's work has identified a range of different aspects that children may include in their discussions of floating and sinking, for the purposes of this study these categories were too broad to capture the differences between the children and therefore these were extended to include more categories. In order to permit a cross-age analysis of children's ideas so that the potential changes that take place over time in frameworks could be explored, each child's response was assessed using the framework categories identified in Table 53.

The frameworks were used in order to categorise the ideas that children discussed in their verbal responses to probes used at the beginning of each floating and sinking activity. The content of children's responses was used as a basis for the categorisation and where the groups of children reached a joint consensus all members of the group was allocated to the same category.

The distribution of the categories across the age groups of participants is shown in Table 54. Interestingly, some of the ideas revealed in the written responses rarely occurred individually as verbal responses, for example, although children in Year 6 sometimes wrote about surface tension as a factor which influences whether or not objects float or sink but they never discussed this factor in their verbal responses. The same was true of upthrust and buoyancy which was included in some of the Year 2 children's written responses but did not feature in the children's other work. Overall, the framework analysis revealed that the Year 2 children most frequently attended to the material properties of the object when discussing floating and sinking and what kind of object would float. In particular, the weight of the object appeared to be the most important aspect for consideration in this age group ( $N = 27$ ; 77%). Only 3 of the children in this age group considered the properties of the liquid in which the object was to be floated as well as the properties of the object.

Intuitive ----- → Scientific	Primary Framework	Secondary Framework	Category
	<b>Non-Relevant and Non-Scientific</b> No physical properties are mentioned or the responses are not relevant to floating and sinking		<b>1</b>
	<b>Object (Material) Properties</b> Focuses on the physical properties of the objects	Weight Air (presence in object) Shape Surface area Density	<b>2</b>  <b>2a</b> <b>2b</b> <b>2c</b> <b>2d</b> <b>2e</b>
	<b>Liquid Properties</b> Focuses on the properties of the liquid in which the objects are placed	Amount of Liquid Surface Tension Density	<b>3</b>  <b>3a</b> <b>3b</b> <b>3c</b>
	<b>Forces</b> Focuses on the forces that act on either the object or the liquid	Gravity Upthrust / Buoyancy	<b>4</b>  <b>4a</b> <b>4b</b>
	<b>Combination Framework</b> Incorporates elements of the three frameworks identified above	Object (material) properties + Liquid Properties  Object (material) properties + Forces  Liquid Properties + Forces  Object (material) properties + Liquid Properties + Forces	<b>5</b>  <b>5a</b>  <b>5b</b>  <b>5c</b>  <b>5d</b>

*Table 53: The possible frameworks of children's ideas for floating and sinking that are evident within the participant groups taking part in this study.*

The results of the analyses of the Year 6 children's verbal responses revealed that by this age there was far greater diversity in the responses that the children revealed. Weight of the object was still considered important for some of the children (N = 12; 27%) but other factors such as the presence of air were also frequently discussed (N = 14; 32%). Within this age group there was evidence of greater consideration of forces as a factor. Interestingly, at this age no children discussed

the link between the properties of the liquid alongside their discussion of the material properties of objects.

Intuitive ----- → Scientific	Category	Year 2 (N = 35)	Year 6 (N = 44)	Year 9 (N = 14)
	<b>1</b> Non-Relevant and Non-Scientific			
	<b>2</b> Object (Material) Properties	4 (11%)	2 (5%)	
	<b>2a</b> Weight	27 (77%)	12 (27%)	1 (7%)
	<b>2b</b> Air	1 (3%)	14 (32%)	3 (21%)
	<b>2c</b> Shape		6 (13%)	
	<b>2d</b> Surface Area		1 (2%)	
	<b>2e</b> Density			
	<b>3</b> Liquid Properties		1 (2%)	
	<b>3a</b> Amount of Liquid			
	<b>3b</b> Surface Tension			
	<b>3c</b> Density			
	<b>4</b> Forces		4 (9%)	
	<b>4a</b> Gravity		2 (5%)	
	<b>4b</b> Upthrust / Buoyancy		2 (5%)	1 (7%)
	<b>5</b> Combination Framework			
	<b>5a</b> Object + Liquid	3 (9%)		5 (36%)
	<b>5b</b> Object + Forces			4 (29%)
	<b>5c</b> Liquid + Forces			
	<b>5d</b> Object + Liquid + Forces			

*Table 54: The distribution of the different floating and sinking frameworks across the different age groups of participants.*

The combinations frameworks were most prominently discussed by the oldest group of children, Year 9, but even at this stage some children (N = 4; 28%) still attended

only to the material properties of the objects in their discussions. However, at this age children more frequently discussed forces such as gravity and upthrust.

Overall the results appear to support the notion that there is a general trend from intuitive and concrete ideas to those that are more scientific and abstract as the children get older. Indeed it was the oldest children who were the most likely to discuss ideas that were not necessarily directly observable such as forces. As with the written responses and the theme analysis there was evidence of only 4 different frameworks in the Year 2 children's data, 9 different frameworks were evident in the Year 6 children's data and 5 different frameworks were evident in the Year 9 data. These finding may represent an overall general trend where children begin with a few ideas, which are then extended to include more aspects before becoming reduced to more complex but less variable responses later. However, it is also important to consider that this finding may have been due to the lower number of participants at Year 9 level. With reference to the previous research detailed in Chapter 3, there appeared to be evidence that as previously indicated the children's ideas about floating and sinking become more scientific over time and the children begin to appreciate that whether or not something floats or sinks may be influenced by a range of factors which include weight but also include aspects related to the liquid.

#### **7.2.5 A Comparison between Children's Drawings, Written and Verbal Responses**

A comparison between the drawings, written and verbal responses that children generated when asked to draw, write or comment why some things float and some sink revealed that for the younger children (Year 2) whilst they found it easy to complete the drawing task (e.g. place one object in a floating and one object in a sinking position) there was a disparity between the contents of their verbal responses and the contents of what they had written. The written responses on the worksheet discussed above demonstrated that children frequently failed to write any response and those that did focused their discussions on the weight of the object as the most important factor. In contrast, verbal responses to probes asking children to discuss why they thought things float and sink revealed that children of this age



whilst still adopting an object-centred frame also considered some additional features including the presence of holes in object, the presence of trapped air inside the object, and the material that objects are made of. As with the younger children all of the Year 6 and the Year 9 children found it easy to complete the drawing task. The difference between the content of written and verbal responses was reduced within the Year 6 children, and was not evident in the responses of the Year 9 children, suggesting that there may be an age effect related to the writing process rather than the underlying frameworks that the children hold. It could be suggested that the demands of the written task make this element of the worksheet more difficult for the younger children to complete and because of this, although the children may hold these ideas they may find it difficult to put these on paper.

### **7.2.6 Changing Children's Ideas**

As with electricity the floating and sinking activities included a conceptual challenge element, namely the demonstration of upthrust and water displacement by pushing an inflated balloon into the tank of water. A second thematic analysis was conducted on the children verbal responses for what they thought floating and sinking was at the end of the work. The results of this analysis for floating (see Table 55) revealed that the younger children (Year 2) still focused their discussions on the position of the object in the water as they had done at the beginning of the activity. Thus, although the children had appeared to accept the information given in the conceptual challenge aspect of the task and, in some cases, although they had discussed this at the time, they had not incorporated these new ideas into their responses by the end. Whilst many of the Year 6 children still discussed the position of the object in the water, many now discussed the role of forces and in some cases the children named the balance between upthrust and gravity as important. These findings appear to support the view that the Year 6 children had begun to incorporate new information drawn from the conceptual challenge aspect of the task into their ideas, thus demonstrating that for this age group the activity was successful. Similar findings were observed in the Year 9 children, with many children now discussing forces in their explanations. Thus, this age group successfully demonstrated more scientific aspects of conceptual change in their ideas.

What is meant by floating?	Year 2 (N = 35)		Year 6 (N = 44)		Year 9 (N = 14)	
	Before	After	Before	After	Before	After
Not sure						2 (14%)
Is not sinking					2 (14%)	
Staying up	3 (9%)	3 (9%)	4 (9%)			
Things that go above the water surface			5 (11%)		6 (43%)	
Staying at the top of the water	12 (34%)	28 (80%)	5 (11%)	16 (36%)		
Things sitting at the surface of the water (but not always)			16 (36%)			
Staying at the top or sometimes in the middle of the water	20 (57%)	4 (11%)	4 (9%)			
When light things stay at the top			5 (11%)			
To do with forces			5 (11%)			
If something doesn't go under the water					3 (21%)	
The water holding something up				5 (11%)		
Force pushing object up				13 (30%)		
Upthrust is more than gravity						4 (29%)
Upthrust and gravity are equal				10 (23%)		3 (21%)
Is something displacing more water than its weight					3 (21%)	5 (36%)

*Table 55: A theme analysis of children's ideas for floating as measured before and after the conceptual challenge element of the study.*

Overall the results of the analysis appeared to reveal a trend where the older children appeared to incorporate the more advanced scientific ideas into their discussions. The Year 6 children appeared to have learned the most from the activities, however, it is also striking that 9 of the Year 9 children had now begun to discuss forces such as gravity and upthrust in their verbal responses.

The thematic analysis for children's ideas about sinking as measured at the end of the activity also revealed that the younger children (Year 2) still used similar description to those provided at the beginning of the activities (Table 56). Suggesting that despite the conceptual challenge aspects of the activities the younger children still perceived that sinking was defined by the movement of the object through the water to the bottom.

What is meant by sinking?	Year 2 (N = 35)		Year 6 (N = 44)		Year 9 (N = 14)	
	Before	After	Before	After	Before	After
Going down slowly	3 (9%)	3 (9%)				
Movement through the water to the bottom	28 (80%)	28 (80%)	25 (57%)	16 (37%)	2 (14%)	
Things that go completely under the water			5 (11%)			
When an object goes straight to the bottom	4 (11%)	4 (11%)			7 (50%)	
When objects are heavy so they go to the bottom			5 (11%)	5 (11%)	2 (14%)	
Object is too heavy for surface tension to hold it						4 (29%)
Gravity making heavy objects sink			5 (11%)			
Falling or being pulled by gravity			4 (9%)	9 (20%)		2 (14%)
Gravity pushing object down				5 (11%)		
Upthrust is not enough				4 (9%)		
Gravity greater than upthrust				5 (11%)		3 (21%)
When an object cannot displace enough water equal to its weight					3 (21%)	3 (21%)
When the density of the object is more than the density of the liquid						2 (14%)

*Table 56: A theme analysis of children's ideas for sinking as measured before and after the conceptual challenge aspect of the activities.*

In contrast, the Year 6 children had begun to include discussions of forces including upthrust and gravity in their responses. These results suggest that following the conceptual challenge aspect of the task some of the children were able to adapt their ideas in order to incorporate more scientific aspects. A similar finding was evident in the responses from the Year 9 children, some of whom now discussed forces and the importance of these for defining what sinking is. Taken as a whole, these results suggest that the conceptual challenge aspect of the task was most successful for the Year 6 and Year 9 children, both years incorporating new information into their existing ideas by the end. For some of the children this included a change in the framework that they applied to the task, thus demonstrating evidence that might be considered to be a form of radical restructuring, whilst for other children these changes signified weak restructuring and no change in the overall frameworks applied.

Critically, however, it is important to highlight that whilst there was some evidence of change in the definitions that children applied when discussing their ideas, a study such as this only provides a snapshot of a specific point in time and it is not possible to discuss whether these changes are long lasting or if they were simply instantaneous. When the age groups of children were compared however, it was possible to highlight evidence of both weak and radical changes in ideas between the age groups. As discussed before, the younger children appeared to focus solely on the weight of the object, whilst the older children begin to incorporate information such as the size and shape of objects which perhaps could be demonstrating evidence of weak restructuring or early precursor ideas regarding density. These findings appear to be consistent with work such as Piaget's (1958) who proposed that older children more readily incorporated more scientific ideas in their discussions.

In order to further explore any changes that may have been made to the children's ideas an evaluation of the frameworks applied during the final probes to the tasks was undertaken. This data is detailed in Table 57. As indicated the results revealed that the Year 2 children demonstrated no evidence of framework change between the beginning and the end of the activities, their ideas remained consistent and focused on the object properties such as the weight and the presence of air in objects. The Year 6 children demonstrated some movement between the frameworks, most notably at the beginning of the activities the majority of the children clustered around the object properties frameworks, by the end of the activities however, the majority of the children ( $N = 26$ ; 59%) were applying a forces framework and some children ( $N = 4$ ; 9%) were using combination frameworks which included discussion of both forces and object properties. This evidence suggests that the children's ideas about floating and sinking were becoming more advanced and scientific by the end of the tasks. A shift in the frameworks applied was also evident in the older children's ideas (Year 9). Whilst at the beginning of the tasks 4 of the children held frameworks that attended to object properties such as weight and the presence of air, these ideas were no longer present at the end of the tasks and all of the children's ideas were contained in more advanced and scientific frameworks such the forces or in combination object and liquid properties.

<b>Intuitive</b>	Framework Category	Year 2 (N = 35)		Year 6 (N = 44)		Year 9 (N = 14)	
		Before	After	Before	After	Before	After
<b>Scientific</b>	<b>1</b> Non-Relevant and Non-Scientific						
	<b>2</b> Object (Material) Properties	4 (11%)	4 (11%)	2 (5%)			
	<b>2a</b> Weight	27 (77%)	27 (77%)	12 (27%)	2 (5%)	1 (7%)	
	<b>2b</b> Air	1 (3%)	1 (3%)	14 (32%)	12 (27%)	3 (21%)	
	<b>2c</b> Shape			6 (14%)			
	<b>2d</b> Surface Area			1 (2%)			
	<b>2e</b> Density						
	<b>3</b> Liquid Properties			1 (2%)			
	<b>3a</b> Amount of Liquid						
	<b>3b</b> Surface Tension						
	<b>3c</b> Density						
	<b>4</b> Forces			4 (9%)			
	<b>4a</b> Gravity			2 (5%)			
	<b>4b</b> Upthrust / Buoyancy			2 (5%)	26 (59%)	1 (7%)	5 (36%)
	<b>5</b> Combination Frameworks						
	<b>5a</b> Object + Liquid	3 (9%)	3 (9%)			5 (36%)	5 (36%)
	<b>5b</b> Object + Forces				4 (9%)	4 (29%)	
	<b>5c</b> Liquid + Forces						4 (29%)
	<b>5d</b> Object + Liquid + Forces						

Table 57: The frameworks of understanding for floating and sinking ideas that the children held at the beginning and the end of the activities.

Taken as whole the results of the analysis investigating changes in the children's ideas during the course of the tasks revealed that it was possible to change the older children's ideas and that these changes frequently occurred at framework level with Year 6 and Year 9 children demonstrating more scientific and abstract concepts at the end of the sessions.

### **7.3 New Approaches to Studying Children's Ideas about Floating and Sinking - Multimodal Group Studies**

In this section the multimodal aspects of the floating and sinking activities are discussed. Initially, the prevalence of what appear to be gestures that are specific to the floating and sinking activity within the children's responses are explored, and then using specifically sampled group studies drawn from the larger corpus of video data the importance of multimodal ideas are explored within the context of the floating and sinking activity. As in the electricity chapter, three groups studies are analysed using the storyboarding technique in order to explore the different levels of communication and what these add to an understanding of children's ideas in this area. The group studies were purposively sampled in order to provide an overview of typical responses for the three age groups. Finally, one group study, Year 6, was further analysed using the timeline analysis approach, as with electricity this group was purposively sampled because of the levels of interaction between the children in the group and the data generated appear to provide interesting findings.

### 7.3.1 Children's Gestures for Floating and Sinking

In order to explore the types of gestures that children used during their discussions of floating and sinking, a content analysis of all of the children's gestures produced when responding to the following probes was completed.

The gestures produced were grouped according to the five categories identified during the pilot study (see Figure 17 in Chapter 5):

- referential;
- representational;
- expressive;
- thinking;
- social.

The prevalence of these gestures during the groups studies which were fully transcribed and the initial and end probes of all of the activities within the total video corpus are shown in Table 58.

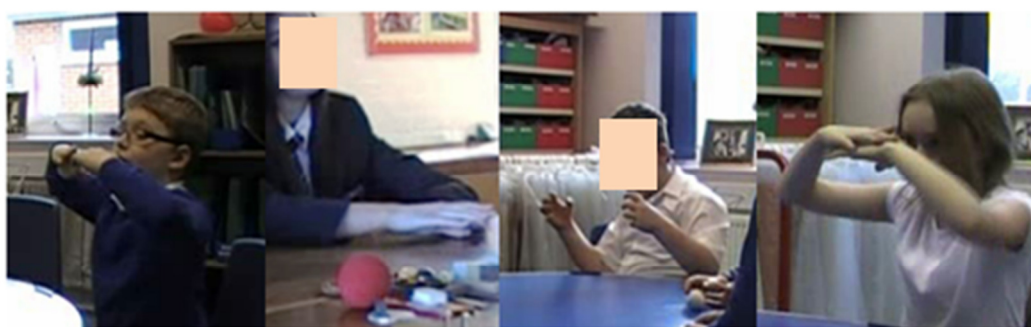
Types of Gesture	Referential	Representational	Expressive	Thinking	Social	Total
Year 2	9	28	6	0	22	65
Year 6	8	79	13	6	29	135
Year 9	9	12	4	8	20	53

*Table 58: The frequency of the different types of gesture that the children produced during the floating and sinking activities.*

No gestures were produced which appeared to fit into new or additional categories and there was some evidence of all of the categories being used within the results, thus suggesting that these five categories identified successfully capture all aspects of the gestures used. The results in Table 58 demonstrate that within the context of the floating and sinking activity representational gestures were produced most

frequently overall and social gestures also appeared more common. However, the prevalence of representational gestures appeared to be influenced by the age of the children and in the Year 9 group, social gestures had a stronger prevalence. Overall the children appeared to use referential gestures less frequently when compared to during the electricity activity.

One key finding from the analysis was that there was consistency between the different age groups of children regarding the gestures that they associated with floating and sinking. Photographs drawn from the group work videos which show the different age groups discussing what floating and sinking are provided (Figure 47 and 48). Typically, the children used stationary hand gestures during their verbal discussions of floating. Often these contained flat hands held at about shoulder height with palms facing downwards, in some cases the children would hold their hands in 'c' and backwards facing 'c' shapes in order to represent boxes. As before these would be held stationary for a few seconds before being released. Finally, some children would hold just one hand out, palm facing downwards and fingers spread wide. The hand would then be moved in a gentle sideways motion for a few seconds before being placed back onto the top of the desk.



*Figure 47: Typical floating gestures produced by the children during the activities.*

When discussing sinking, the children typically used downward motions in order to show what they thought sinking was like. Photographs drawn from the activities which show the typical gestures that the children used are provided (Figure 48).

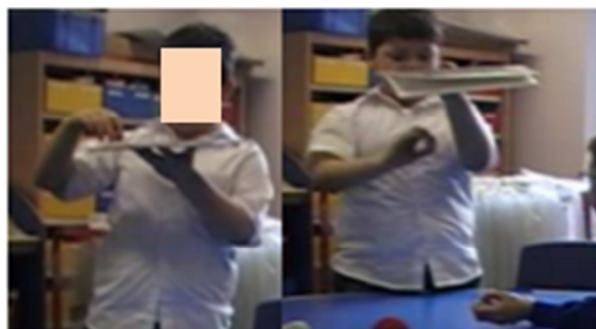




*Figure 48: Typical sinking gestures produced by the children during the activities.*

Often these gestures were made using just one hand, which was initially held at shoulder height and then lowered towards the top of the table at which the children sat. The speed of hand movement did vary, with some children making a fast sudden movement towards the top of the table and others making a slow gentle motion which would end just above the top of the table.

During the activities some children also used props from the setting in order to represent their ideas for floating and sinking (Figure 49). Figure 49 shows one such example, here a Year 2 boy supported his discussions of what he thought floating and sinking was by using a book to represent the surface of the water. In the first image Adam placed a 'floating' object on top of the book that he was holding flat. Whilst in the second image Adam, moved the object below the book in order to show what he thought sinking was.



*Figure 49: Year 2 boy, Adam, uses props in order to show what he thought floating and sinking was.*

As with electricity, children used referential gestures during their discussions of floating and sinking. However, this type of gesture appeared less frequently during the floating and sinking activity. Referential gestures were typically used by the children in order to draw attention to the objects that they were using to support their discussions.

Time	Person	Verbal Report	Gesture
03:20	Thomas	I've drawn a pencil and a rock.	Thomas points to his drawings on his worksheet.

*Table 59: Year 2 boy, Thomas, uses a representational gesture to highlight what objects he had included in his diagram.*

In this example of a referential gesture, Thomas, a Year 2 boy, can be observed using a referential gesture in order to draw attention to the objects that he drew in his diagram (Table 59; Figure 50). It is proposed that this gesture which anchors his discussion to the drawing is useful for two reasons. Firstly it draws the attention of the listener or viewer to the product of his effort and provides a supporting context for his verbal response. Secondly, the information drawn from both the verbal response and the gesture serve the purpose of providing a definition for what the items that he has drawn are. One interpretation of this data is that this is a deliberate act by Thomas in order to ensure that it is clear what the objects that he has drawn are. Thomas used referential gestures frequently during his discussions.



*Figure 50: Thomas' referential gesture (Table 59), Ciaran's representational gesture (Table 60) and Thomas anchoring his discussion to an object (Table 62).*

Within the context of the floating and sinking tasks representational gestures were also used. In one example Ciaran, a Year 2 boy, used his hand to make a downward motion as he discussed his ideas for the kind of things that sink (Table 60; Figure 50). Ciaran stated that “very heavy stuff goes” and as he said this he made downward movements with both of his hands. It is proposed that the gesture in this example also helps to add clarity to Ciaran’s discussion. Without the downward gesture it would not be clear where exactly Ciaran thinks the “heavy stuff” does go. Using the translation of the gesture in conjunction with the content of the verbal response it is clear that Ciaran thinks that heavy objects go down to the bottom of the liquid in which they are being placed.

Time	Person	Verbal Report	Gesture
01:00	Ciaran	Very heavy stuff goes.	As he speaks Ciaran makes a downward motion with both of his hands.

*Table 60: Ciaran, a Year 6 boy, uses a representational gesture in order to show how he thinks heavy objects move through water when they are sinking.*

Ciaran’s representational gesture is just one example of many that could be drawn from the corpus of video generated by this study. What is clear is that children do use such representational gestures in order to complete their discussions or add new information to discussions that may not be readily evident. Expressive gestures were used by the children to highlight values such as strength of responses. This particular form of gesture occurred less frequently than representational or social gestures during the floating and sinking activity.

An example of such expressive gestures could be observed among the Year 9 children as Angela used an expressive gesture in which she spreads out her fingers, clenches her hands and then spread the fingers again (Table 61; Figure 51). This expressive gesture, containing the repeated movement of her fingers, shows the behaviour of a floating object. What is interesting is that in this case the gesture extends our understanding of Angela’s ideas beyond the content of her verbal response. Notably, Angela appeared to struggle to verbally define what floating is

without using the word float. Angela's gesture, however, shows that according to her ideas a floating object sits in the water and her flat hands represent the behaviour of the object which remains stationary.

Time	Person	Verbal Report	Gesture	Other Non-Verbal
00:39	RS	Okay so what do you think floating is?		As the RS begins to ask the question Zoe removes her hands from her face and places them on the table.
	Angela	It's where the object like, it floats.	As she speaks Angela raises both of her hands slightly into the air, spreads her fingers out so that the hands are held straight and then pulls them back into clenched fists. She then spreads them out again and lowers them to the table.	

*Table 61: Angela, a Year 9 participant, uses an expressive gesture in order to show her understanding of how a floating object behaves (RS = researcher).*

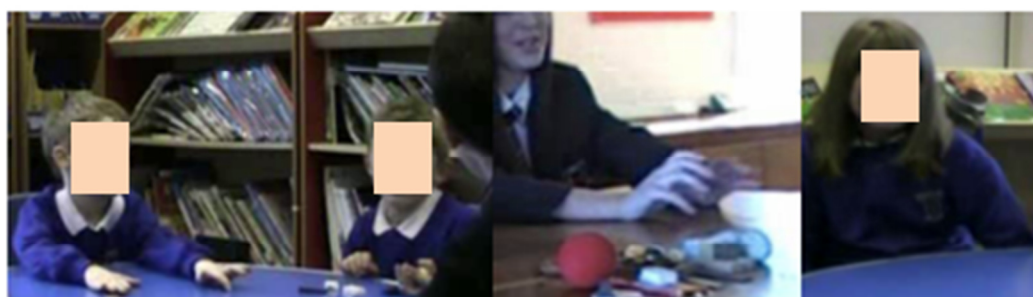
The use of gesture to extend the meaning portrayed in the content of speech was a frequent occurrence within the video corpus. However, one interesting finding was that for the floating and sinking tasks, thinking gestures only appeared to be used by the older children (Years 6 and 9). It is unclear why this occurred, but perhaps one explanation may be that the younger children often picked up objects when they were discussing their ideas and this action may in some way have either reduced or replaced the necessity for the thinking style gesture to occur. For example, during

one Year 2 activity, a group were discussing what kind of things sink. Thomas and Ciaran both proposed that heavy objects would sink. As they developed their ideas Thomas could be seen to pick up the ball of plasticine. His accompanying verbal discussion highlighted that he thought that this object would sink but he failed to complete the sentence. He did however, keep hold of the ball of plasticine (Table 62; Figure 51).

Time	Person	Verbal Report	Gesture	Other Verbal	Non-Verbal
01:11	Thomas	Maybe that will sink cuz...	Thomas picks up the ball of plasticine.	Nicola reaches across the table to pick up the bouncy ball.	

*Table 62: Thomas, a Year 2 child, anchoring his discussion to an object that he was holding in his hand.*

It is difficult to support with certainty the view that Thomas' action of holding this object in some way replaced the typical thinking gestures that were produced by the Year 2 children when discussing electricity but it may have. However, it is also possible that because the floating and sinking activities were more 'hands on', concrete and familiar, the younger children may not have felt that the topic posed too much difficulty for them. In addition, it is possible that any thinking gestures produced by this age group may have occurred during the aspects of the tasks that were not fully transcribed.



*Figure 51: Thomas anchors his discussion to an object (Table 62), Angela using an expressive gesture (Table 61) and Alice's thinking gesture (Table 63).*

Clear evidence of thinking gestures did, however, occur in the Year 6 age group and whilst some thinking gestures contained finger drumming they also sometimes contained what appeared to be rocking motions. Alice's group had been discussing how the shape of a boat helped them to float and how there was something on the bottom of a boat that helped them to do this. When probed further for what the children thought it was Alice who stated that she could not remember the name and as she made her verbal response she sat on her hands and rocked slightly from side to side (Table 63; Figure 51). As soon as she has finished speaking Alice stopped the rocking motion and removed her hands. It was suggested that this repeated motion was not an externalised form of stress, Alice's voice didn't change pitch and her facial expression did not change, but this was rather just an externalised form of her thinking. The gesture ended at the same time as her verbal response which supports the notion that in some way the two modes of communication are connected. It would appear that the rocking motion when used in this way signified to the onlooker that Alice is unable to provide any further comment that was relevant to the current discussion but as the gesture ended when her speech did it is proposed that she still remained open to joining in with other discussions and Alice did continue on during the activity to play a very active role.

Time	Person	Verbal Report	Gesture
02:08	Alice	I can't remember what they are called.	Alice sits on her hands and rocks a little from side to side.

*Table 63: Alice, a Year 6 child, using a thinking gesture during her discussion of how the shape of the bottom of a boat helps it to float.*

Thinking gestures were useful for revealing the time during which the children were considering their responses and required additional thinking time. They could also signal when the children had reached the limits of their ability to respond and that the discussion should move on. However, social gestures could also reveal important cues about children's ideas through moments when they may have uncertainty and moments when they may require support from peers or tutors. Within the context of the floating and sinking activities, social gestures appeared within all of the age

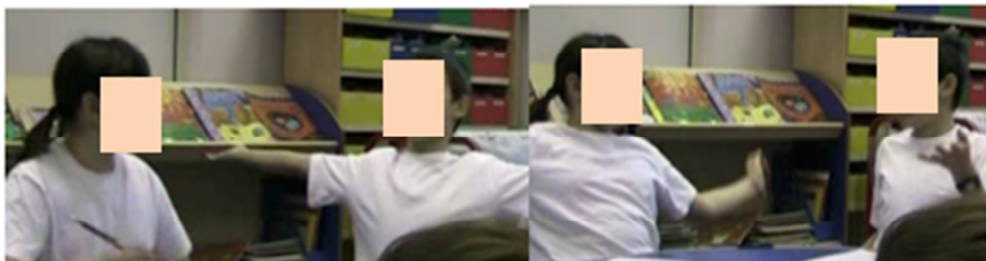
groups and were the second most common gesture found overall and most common in Year 9. Some of the social gestures that the children used were complex and appeared to contain many different elements. The following Year 2 social gesture contained this level of complexity and occurred as the children were discussing their predictions for which objects would float and sink (Table 64). Thomas had predicted that the pumice stone would sink because it was quite heavy. His verbal response confirmed his certainty about this result and he covered the object with his left hand as he spoke. In his social gesture he shook his head and Ciaran, another member of his group, looked over at him and then looked down to the table. Ciaran's social gesture was interesting because it appeared to show that he was not so sure of Thomas' certainty about this result. By looking down at the table Ciaran appeared to indicate that he did not want to engage in this debate with Thomas, perhaps because he disagreed with the prediction or perhaps because he was not so certain. Ciaran's looking behaviour towards Thomas could also be interpreted as a social challenge but Thomas did not respond. Whilst it was difficult to be entirely certain what this social gesture meant it was clear that there was some form of meaningful social interaction occurring between these two boys.

Time	Person	Verbal Report	Gesture	Other Verbal Non-Verbal
12:57	Thomas	My idea about this is definitely gonna be right.	As he speaks Thomas puts his left hand over the pumice stone.	Thomas shakes his head as he speaks and looks at the researcher – Ciaran looks over to Thomas, he then looks down at the table.

*Table 64: Transcript extract showing how Thomas and Ciaran, Year 2 children, used social gestures during their discussions of what items they think will float and sink.*

Evidence of more complimentary social gestures could be observed within the Year 6 video corpus. In the example below, Daniel and Sarah used social gestures amicably during their participation in the activities (Table 65; Figure 52). The interaction of focus here occurred as the children were completing the drawing task.

Sarah questioned whether it was okay for the children to draw a human body. The researcher confirmed that the children were free to choose anything that they would like to draw and this prompted a discussion about whether or not people float or sink.



*Figure 52: Daniel and Sarah's social gestures used during their discussion of whether or not people float or sink (Table 65).*

As Daniel spoke he imitated a person floating in water. As he did this he looked at Sarah who had begun to mimic his actions. Sarah agreed both verbally and in her social gesture with the ideas that Daniel suggested (e.g. that people can float or sink depending on what they are doing in the water). Sarah's smile provided additional social support for Daniel's proposal.

Overall the results of the analyses of gesture show that it is possible to identify all five categories of gesture in the video materials drawn from the floating and sinking activity. In some cases the gestures used appeared to be task specific and highly related to floating and sinking, in others, for example the social gestures, there appeared to be consistency across the science topics.

Time	Person	Verbal Report	Gesture	Other Non-Verbal
2:17	Sarah	Can you draw a human body?		
	RS	You can draw whatever you want I really don't mind.		
	Daniel	Well sometimes you sink and sometimes you float, cuz if you go like that and stick your bum up then you float.	Daniel imitates floating in the water by spreading both of his arms wide and pushing his chest forward.	He looks to Sarah who is also spreading both of her arms.



			As he says "float" he moves both of his arms and uses his left hand to indicate an upwards movement, his hand is palm upwards.	
	Sarah	Yeah.		Smiles as she looks at Daniel.

*Table 65: Transcript extract showing the social gestures shared by Daniel and Sarah, two Year 6 children, during the floating and sinking activities (RS = researcher).*

The analyses of gesture revealed that sometimes these appeared to be redundant to the children's verbal discussions of their ideas, other times the gestures appeared to contain supporting information for the content of speech and finally the gestures that children produced could sometimes carry meaning that was not stated or provided elsewhere. Such findings are consistent with the work of Crowder and Newman (1993) who found similar results in their study of children's use of gesture. It is perhaps this last form of gesture, those that go beyond the meaning stated in other response types that are the most valuable in terms of helping to understand the ideas that children have for floating and sinking. The analysis of these gestures was fundamental to providing a full understanding of children's ideas.

### **7.3.2 Group Studies for Floating and Sinking**

In order to explore what the multimodal analysis of data could add to the discussions and debates regarding the processes that support conceptual change, 3 group studies were purposively sampled from the entire corpus of audio / video data as they were with electricity. One group was selected from each age studied and the groups were sampled according to whether the participants used non-verbal gestures within their discussion. As almost all of the children gestured at some point during the activities, sample cases were drawn from those groups where the gestures appeared to perform an important role in the children's discussions (e.g.

gestures were used to support, complete or elaborate on verbal explanations when the children were talking). In order to gain a balanced view, these group studies included examples where changes were evident following the challenge of children's ideas alongside examples where no change was evident and examples where the activities did not progress as expected. By taking this approach, the analyses presented here are particularly representative of typical classroom activities where there may be great levels of variability in the other factors that can impact on the learning and the outcomes that may result directly from teaching.

In all instances the group studies chosen for further analysis were transcribed fully. In order to reduce the data to a manageable level a storyboard was produced for each group (Figure 54 Year 2, Figure 62 Year 6 and Figure 64 Year 9). These storyboards captured key events within the activities, important ideas and discussions that the children had and the frameworks of understanding for floating and sinking that were evident at the beginning and end of the activity. The storyboard was also used to highlight 'critical moments' where the discussions between the participants appeared to have an impact on the children's learning or where the different modes of communication played an important role in either communicating children's ideas or where there was contrast between the content of both modes. The critical moments identified during the storyboard analyses were subjected to transcription across three conditions: sound only, image only, and sound and image together.

### **7.3.3 Year 2 Group Study**

The Year 2 group study focused on four children (two female, two male) called Tina, Nicola, Ciaran and Thomas from Village Primary School. The activity lasted approximately 40 minutes from start to finish. The activity was held in the school library area which contained two large round tables. The children were encouraged to sit around one of the tables and once the activity began the researcher moved the water tank to this table in order for the children to complete the tasks. The group had been put together by the Year 2 class teacher in the school, in accordance with the researcher's request the teacher had allocated the children so that each group contained a range of different academic abilities.

The initial analysis presented here focused on the multimodal representations that children brought when first discussing their ideas about floating and sinking. The Year 2 storyboard (see Figure 54) details the ideas contained within the children's verbal responses to probes of their knowledge, the content of their drawings, their written responses to the sentence completion task and the gestures that they use as they talk. All of the children agreed in their verbal responses that floating or sinking depended on the position of the object in the water. All of the children agreed that the weight of the object was the most important factor for deciding whether or not items would float or sink. In their drawings, all of the children drew two items, one in the floating position (all children drew an object at the surface of the water in the diagram) and one in the sinking position (all of the children drew an object at the bottom of the tank in the diagram). The representations that the children used during the drawing task possibly revealed a dichotomous relationship between the ideas of floating and sinking; notably floating was drawn at the surface of the water and sinking at the bottom of the tank. This group of children drew a number of different objects including pencils, racks and people, the latter causing debate within the group regarding whether or not people float or sink.

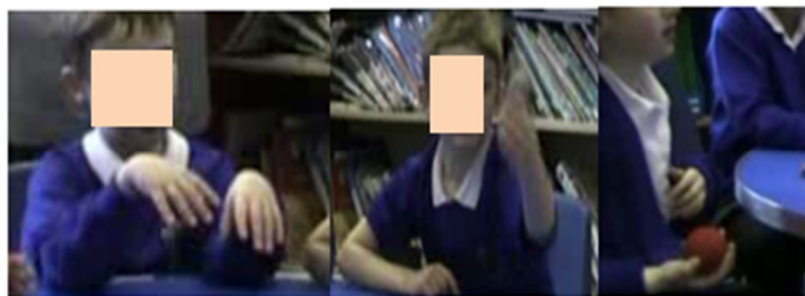
None of the children in this group produced a written response to the sentence completion task. The gestures produced were interesting. At the beginning of the activity Ciaran produced a stationary gesture whilst discussing a floating object and a gesture containing a downward motion when discussing sinking. These gestures were used to represent the objects that Ciaran was discussing and they were a non-verbal way of extending the ideas that he presented in his speech. In the extract shown below (Table 66; Figure 53) Ciaran verbally states that 'very heavy stuff goes...', the gesture is particularly useful in this instance as it enables us to see how Ciaran thinks that the object will move in the water and finishes his train of thought. Ciaran used both of his hands to make a downward movement. This gesture included information that was not found in his speech and is fundamental for extending and clarifying our understanding of his ideas about what type of objects sink and indeed how these objects actually move in the water.

Time	Person	Verbal Report	Gesture
01:00	Ciaran	Very heavy stuff goes.	As he speaks Ciaran makes a downward motion with both of his

			hands.
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*Table 66: Transcript extract showing Ciaran's use of a representational gesture during his discussion of type of objects he thought would sink.*

During this initial stage of the activity, Ciaran was the only child to produce a gesture that represented his understanding of the behaviour of objects but another member of the group, Thomas, frequently picked up and held objects as he was forming his verbal responses in discussion.



*Figure 53: Ciaran's representational gesture (Table 66), Thomas using objects during his discussions (Table 67) and Nicola using a weighting gesture to test the weight of an object (Table 68).*

For example, Thomas identified rocks as objects that will sink. As he did this he picked up and held the pumice stone that formed part of the material sorting task (Table 67; Figure 53). This type of handling of objects could be proposed to occur by chance but because he selected the pumice stone when discussing rocks it appeared that Thomas was anchoring his verbal response to the physical object. Thomas did this frequently throughout the duration of the activity.

Time	Person	Verbal Report	Gesture
01:07	Thomas	Rocks cuz they're heavy.	As he speaks Thomas picks up

			the pumice stone and holds it in the flat of his hand.
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*Table 67: Transcript extract showing how Thomas, a Year 2 participant, frequently anchored his discussions to physical objects when discussing what items he thought would float and sink.*

Overall this group were all classified as having frameworks that corresponded to 2a object properties framework in the categorisation system developed in Section 7.2.4 of this chapter for their floating and sinking ideas. The 2a framework identified that the children focused on the properties of the object when they were discussing floating and sinking. Specifically these children focused their discussions on the idea of weight of the object and the way that this influences whether an object will float or not. All of the children agreed that light objects floated and heavy objects sank. When considering all of the factors that may be related to the topic the children appeared to consider only the location of the object and at no time discussed the properties of the liquid or the forces that may have been involved.

When undertaking the materials sorting task, the children positioned all of the items that 'felt' light into the float pile, all heavy items into the sink pile, and when they are uncertain about the weight of an object they placed it into the 'don't know' pile. The blocks of hard and soft wood did, however, instigate some debate within the group. Thomas insisted that they would float, whilst Nicola thought that they would sink. The children actively moved the wood between the piles until the researcher suggests that perhaps they should consider putting them on the 'don't know' pile. Nicola moved the wood to this location. When Thomas was probed for why he thought that the wood would float he stated "*well it's not really that heavy is it?*" When Nicola was asked why she thought it would sink Tina stated "*Because it might sink, we don't know*". Interestingly as she spoke she picked up the small piece of snake wood, moved it twice between her hands and then placed it back onto the 'don't know' pile.

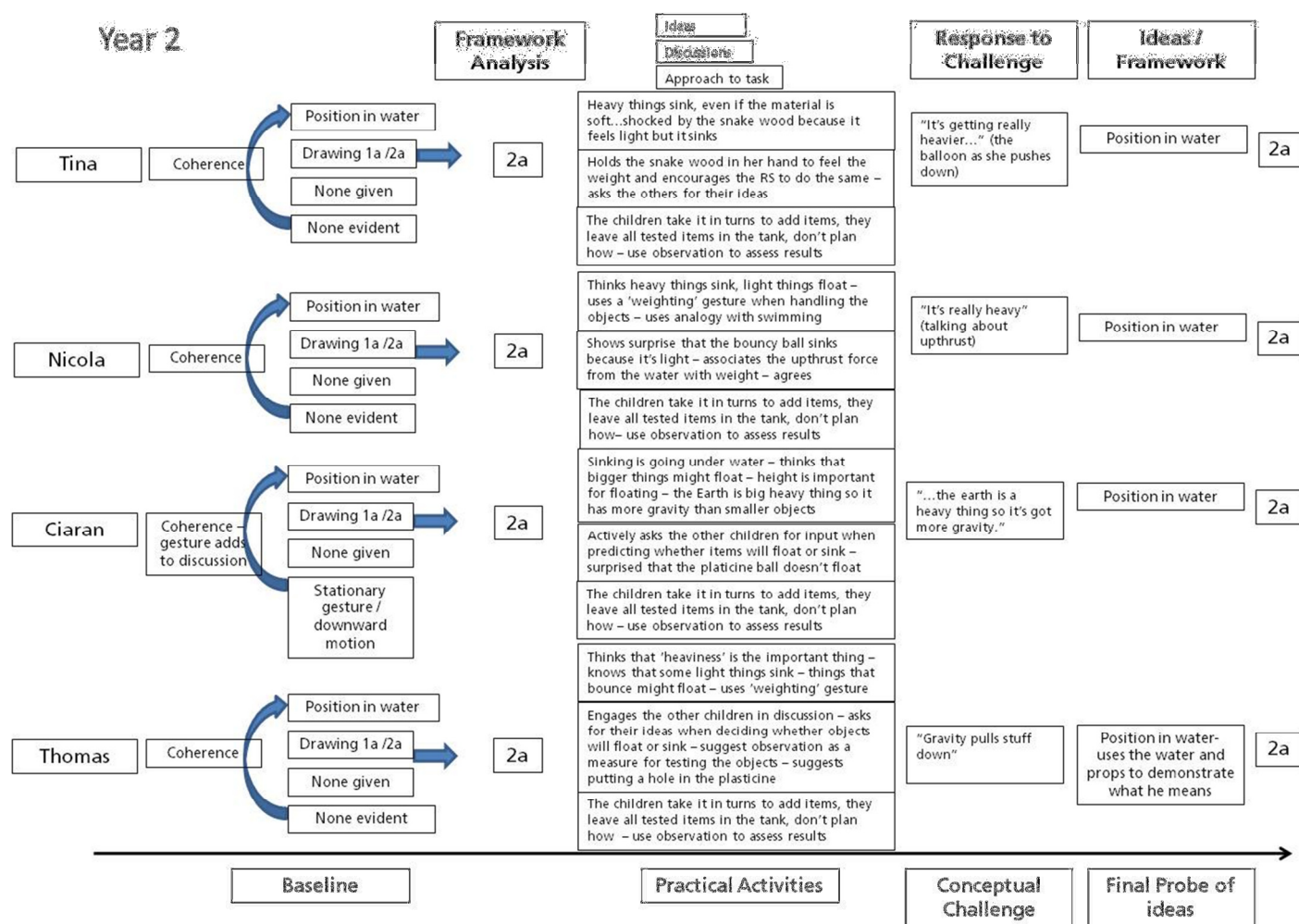


Figure 54: Storyboard for Year 2 Group Study Analysis.

As the children worked through the materials sorting activity one interesting gesture occurred, this gesture appeared to represent weighing scales. What was interesting about this gesture was that it appeared not only with this age group of children but with the older children too (Year 6 and 9). In the example presented in Table 68 (Figure 53) Nicola was discussing the reasons why the children have allocated certain objects to the ‘float’ pile.

Time	Person	Verbal Report	Gesture
09:15	Nicola	Well we’ve got a ball [the red sponge ball] we’ve said it will float because it’s not that heavy.  We think that one is... [tests the weight in her hand and then puts it with the middle pile on the table] ...we don’t know about that one.  We know this one will float so we’ve put that one there.	As she speaks Nicola picks up the red sponge ball, the ball is held in the palm of her hands, she moves her hand slowly up and down as though testing the weight of it. Repeats the same weighing gesture again.

*Table 68: Nicola, a Year 2 child, uses a representational gesture when discussing the items that she thought would float and sink.*

The weighing gesture did appear to serve some function in Nicola’s decision making process and later as the activity moved on the children even encouraged the researcher to use a similar gesture or action in order to feel the weight of an object that had surprised them.

As the children tested the materials they took it in turns to add new items, they left all of the materials in the water tank and only removed them at the end. Unlike the older children, this group did not plan or discuss how to add the materials to the water but they did agree that how they would decide if an item floated or not would be through observing its behaviour in the water. If the item moved to the bottom of the tank the children assessed it as sinking and if it stayed at the top it was considered to be floating. Overall, the children were fairly accurate in the way that they classified the materials with the exception of a few items. When asked to comment on the

materials that surprised them, Nicola highlighted that she was surprised by the behaviour of the 'bouncy' ball because it was 'light'. As Nicola spoke she clarified which objects she was discussing by using a referential gesture to point. Thomas expressed his surprise at the plasticine sinking and he made the suggestion that if a small piece were removed from the ball then perhaps it would be able to float. Finally, Tina highlighted her surprise that the snake wood sank. The snake wood was deliberately chosen because although it was small and felt light it sank in the water; it was exactly these qualities that surprised Tina. The extract below (Table 69; Figure 55) shows her discussion and her non-verbal behaviour (e.g. Tina asks the researcher to hold the snake wood so that she can feel the weight too before removing the object and throwing it back in the water to see what happened).

Time	Person	Verbal Response	Gesture
15:19	Tina	Feel this [the snake wood] light isn't it but look.	Tina hands the snake wood to the researcher, the researcher holds the snake wood in her hand for a second, Tina then takes the piece of wood from the RS and throws it into the water where it sinks.

*Table 69: Transcript extract showing Tina encouraging the researcher to hold the piece of snake wood that has surprised her.*

When challenged to manipulate the plasticine in order to see if the children could make it float rather than sink they tried a number of different shapes. First they flattened the plasticine until it was thin, then they tried ball shapes and finally a hollow ball shape. When the children began to struggle with the task the researcher offered to help to make a shape which would float. The children agreed and the researcher made a bowl shape. When probed as to why the children thought that the plasticine now floated Thomas proposed that the material was now lighter.





*Figure 55: Tina encourages the researcher to feel the weight of the snake wood (Table 69), Ciaran uses a representational gesture as he discusses the Earth (Table 70) and Tina anchors her discussion to an object (Table 71).*

When the children's ideas were challenged through the demonstration of water displacement and upthrust using the inflated balloon, the children associated the upthrust force with weight and Nicola proposed that pushing the balloon into the water was heavy. During this part of the activity, the children revealed a good understanding of gravity and its effects (e.g. that gravity pulls things down), and they also demonstrated that they understood that gravity can be dependent on the object. Interestingly, Ciaran proposed that heavy things have more gravity. He helped to support his ideas by using a representational gesture in which he used both hands to form a circular shape that he associated with the Earth (Table 70; Figure 55).

Time	Person	Verbal Report	Gesture
29:30	Ciaran	Cuz the earth is a heavy things so it's got more gravity.	As he says Earth Ciaran uses both of his hands to make a circular shape, he holds this for a second and then lowers his hands.

*Table 70: Transcript extract showing Ciaran using a representation gesture during his discussion of gravity.*

However, despite showing an understanding of the forces introduced during the conceptual challenge aspect of the task, this group demonstrated no evidence of conceptual change when probed at the end of the activity. The children still all

proposed that floating and sinking was to do with the position of the object in the water and that 'soft' things float and 'hard' things sink. The children's ideas at the end of the activity were still categorised as a 2a object centred framework which focused on the weight of the object.

In terms of exploring the gestures of individual children the evidence suggested that overall, Tina frequently used gestures during her discussions. These gestures appeared to take many forms. She frequently handled objects as she spoke and often spent time looking at these in detail. Table 71 shows one occasion when she does this.

Time	Person	Verbal Report	Gesture
10:45	Tina	Because it's like the same as this one.	Tina holds the ring in her hands and inspects it as she speaks.

*Table 71: Transcript extract showing Tina anchoring her verbal discussion to a physical object during the activities.*

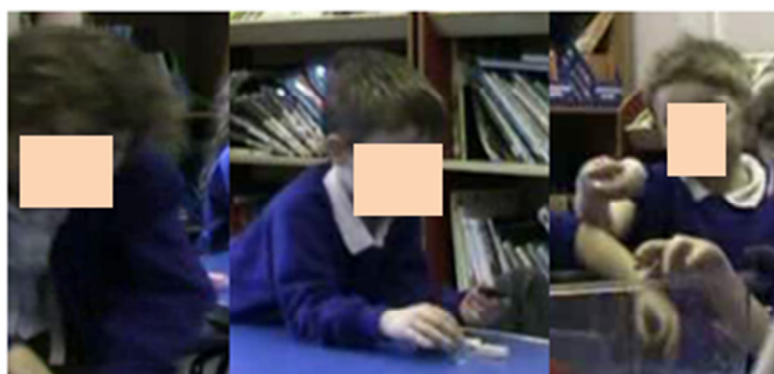
Nicola was a fairly quiet member of the group. However, once the activity moved onto object sorting she became more active and expressed surprise when the objects did not behave as she anticipated. Nicola did gesture sometimes during her discussions but not all the time. The example in Table 72 (Figure 56) Nicola imitated swimming as she discussed the link that she perceived between a person swimming in the water and objects floating and sinking.

Time	Person	Verbal Report	Gesture
02:54	Nicola	Sometimes when you are going under water you get a bit stressed but you don't sink right to the bottom.	As Nicola speaks she stands up and then mimes swimming.

*Table 72: Transcript extract showing Nicola miming a person swimming, the gesture is used to support her verbal discussion.*

Ciaran tended to follow Thomas' lead during the activities, however, he did ask the other children for their ideas when they were undertaking the sorting activity. Like the

other children Ciaran also frequently handled the objects as he discussed them and decides on their behaviour (Table 73; Figure 56).



*Figure 56: Nicola mimes swimming as she discussed floating and sinking (Table 72), Ciaran handles objects as he decides on how they will behave in the water (Table 73) and Thomas holds a surprising object in his hand as he discusses it (Table 74).*

The transcript extract in Table 73 (Figure 56) provides one example of this form of behaviour, here Ciaran was deciding whether a plastic disk would float, he moved the object around in his hands as he spoke and then placed it back onto the top of the table once his discussion is completed.

Time	Person	Verbal Report	Gesture
12:04	Ciaran	Won't float.	Ciaran turns the clear plastic disk around in his hands and then puts it back on the table.

*Table 73: Transcript extract showing Ciaran handling a plastic disk as he decides whether it will float or sink.*

Finally, Thomas also frequently anchored his verbal discussions to the manipulation of the physical objects provided. Thomas introduced a gesture which appeared to represent weighing scales. He also used the objects provided to clarify his intended meaning. In the example provided in Table 74 (Figure 56) Thomas was discussing his surprise that the plasticine did not float. In his verbal discussion he did not identify the material but he did pick up the plasticine and held it in his open hand so

that it was clear what he was talking about. This use of the object in order to reduce misunderstanding appeared to frequently occur within this particular group of children.

Time	Person	Verbal Report	Gesture
15:05	Thomas	I'm surprised about this.	Thomas picks up the ball of the plasticine from the bottom of the water tank and holds it flat in the palm of his hand.

*Table 74: Transcript extract showing Thomas anchoring his discussion to an object that surprised him.*

Overall, the Year 2 group study demonstrated how the children in the age group used the objects as props in order to complete their verbal discussions. It also helped to illustrate the way that the children in this age group appeared to anchor their discussions of floating and sinking to the objects rather than to the liquid in which the items were placed. No group studies within this age range completely changed their ideas about floating and sinking. While the children frequently appeared happy with the concepts introduced and able to understand them, they did not incorporate these into their later discussions.

### **7.3.4 Year 6 Group Study**

The Year 6 group study focused on five children (three female, two male) called Sarah, Daniel, Alan, Lucy and Ellie from Village Primary School. This group study lasted approximately 50 minutes from start to finish. The activity took place in the school library, the layout of which is described in the Year 2 group study earlier. The group had been defined by the class teacher and at the request of the researcher contained a range of different academic abilities. The group worked well together and frequently collaborated in order to generate ideas and to support each other in the completion of the tasks. An overview of this case study is available in the storyboard Figure 62.

When asked, all of the children agreed that floating and sinking could be observed with reference to the position of objects in the water. The children proposed that floating was defined by an object staying in the water and not going under it while sinking was defined as occurring when an object became submerged. All of the children in this group produced drawings that included two objects: the floating object was always drawn on the surface of the water and the sinking object was always drawn at the bottom of the tank. As with the Year 2 group study, the drawings produced by the children in this group appeared to show a clear dichotomous relationship between floating and sinking. When probed about this, however, the children agreed that sinking objects did have to touch the bottom or they would be considered as floating. The children drew a range of objects including a canoe and a speedboat in the floating position, and a coin and a rock in the sinking position. All of the children in this group gave written responses to the sentence completion task which are provided as follows:

*There is a big surface area.* (Sarah)

*They are spaced out... there is air in it.* (Daniel)

*They are light and will float easily and doesn't have air.* (Alan)

*Of the air inside them.* (Lucy)

*They are light and it doesn't weigh the object underwater.* (Ellie)

These responses revealed that the children had slightly different ideas for what makes objects float ranging from the surface area of an object to its weight. The results to the sentence completion task for things that sink were almost the exact opposite and included:

*Not a big surface area.* (Sarah)

*There is no air in it and it is heavy.* (Daniel)

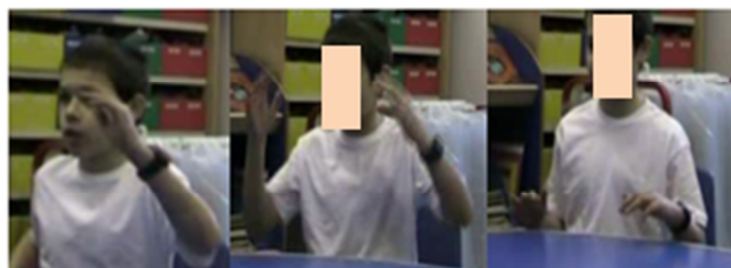
*They are heavy.* (Alan)

Lucy and Ellie failed to complete this sentence. A number of gestures were produced by the children during the early discussions of floating and sinking. For example, Daniel used two interesting gestures during his discussion of what he thought

floating was. The first gesture, a flicking motion, accompanied his verbal discussion of an object that sits on the surface of the water. One interpretation of this data is that the flicking motion that Daniel used was intended to represent the object at the surface of the water (Table 75; Figure 57). Thus this gesture added to the meaning portrayed in his verbal response. The subsequent gesture that accompanied his verbal responses of “*things that stay on the water and which don’t go under it*” appeared to initially represent a stationary object before moving into a demonstration of the way that an object would move if it were to go under the water. This representational gesture appeared to add meaning to the content of Daniel’s verbal speech and allowed us to see how he thought such an object would behave.

Time	Person	Verbal Report	Gesture
00:11	Daniel	Erm, all things that go above the surface, water surface.	Daniel uses his left hand to make a gesture which begins in line with his shoulder, his hand makes a quick flick forward, he then lowers his hand to beneath the table.
		Things that stay on the water and which don’t go under it.	Uses both hands, held at shoulder height to make a cupping motion and as he says “under it” push both hands downwards as though moving through a substance.

*Table 75: Transcript extract showing Daniel using a number of representational gestures in his discussion of what he thought floating was.*



*Figure 57: Daniel’s representational gestures used to show how he thought floating and sinking objects behaved.*

Another interesting gesture produced at this stage in the activity represented the surface area of an object and was produced by Sarah as she discussed her ideas about how the surface area of the object could help it to float (Table 76; Figure 58).

Time	Person	Verbal Report	Gesture	Other Non-Verbal
1:15	RS	So is it the air in a boat that helps it to float?		Sarah puts her hand up, as she does this Lucy reaches across the table and picks up the pumice stone – Sarah extends her arm even further.
	Sarah	Is it the surface area? Like erm at the bottom of something if it's like spread out it's easier for it to float.	Sarah uses her right hands to make a circular movement across the surface of the table as she speaks.	

*Table 76: Transcript extract showing Sarah using a representational gesture in support of her discussion about surface area (RS = researcher).*



*Figure 58: Sarah's representational gestures for surface area (Tables 76 and 77).*

Overall, the children's ideas at the beginning of the activity were classified as 2b for all of the children. The 2b framework (as defined by the Framework developed in

section 7.2.4) which was related to the object properties and in this group the children appeared to focus on the properties of the object such as its weight or the presence of air in the material rather than the properties of the liquid in which the object was placed.

Interestingly, Sarah did demonstrate an early idea that may relate to, or be a precursor to, the concept of the upthrust force which is exerted by the water although she did not recognise it as such. In this discussion Sarah linked her ideas about surface area to the difficulty with which an object with a large surface area could be made to sink (Table 77; Figure 58). This representational gesture used by Sarah appeared to support her discussion and added to the information to that presented in her speech.

Time	Person	Verbal Report	Gesture
01:26	RS	Why do you think it might be easier for it to float if it's more spread out?	
	Sarah	Cuz then there isn't just...cuz then its spread out over lots of water so then it'll be harder to push it all down to make it sink.	Sarah uses her right hand to make a circular motion across the top of the table and when she begins to say "push it down" she raises this hand from the top of the table and makes a downward motion, her hand is flat and the palm is facing towards the table. As she stops speaking she puts her hand on her leg.

*Table 77: Transcript extract showing Sarah using representational gestures during her discussion of the characteristics of floating objects (RS = researcher).*

When completing the material sorting task, the group engaged actively in debate, they agreed that the items that they have placed into the sink pile were heavy or may sink because of their shape. Lucy proposed that some objects may sink more slowly than others and that this may, in part, be determined by their shape. Daniel extended this discussion and used a complex gesture in order to support his articulation. The



extract in Table 78 (Figure 59) shows Daniel discussing how some shapes, for example, those that are like a parachute might take longer to sink. Daniel's representational gesture which is used to show how such an object might behave showed how he thought the object may move through the water.

Time	Person	Verbal Report	Gesture
11:19	Daniel	Cuz of the area space, if you had like a parachute that's like that...then it will take longer.	Daniel uses both of his hands to make a slow downwards movement, palms are facing down, hands stay about a shoulder width apart...ends gesture when both of his hands reach the table surface.
		Like if you put A4 paper in then you have to push the middle bit down and the other ends come up.	Daniel uses his hands to make a slight upwards gesture.

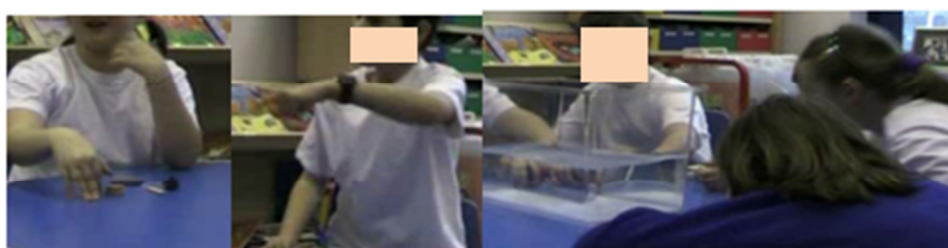
*Table 78: Transcript extract showing Daniel using representation gestures during his discussion of sinking objects.*



*Figure 59: Daniel's representational gestures to show how he thought parachute shaped objects might sink (Table 78) and Sarah's representational gesture about sinking objects (Table 79).*

Gestures such as this are particularly helpful for revealing greater detail in terms of the children's ideas. The children also proposed that objects floating and sinking in water behaved in a similar way to objects floating and sinking in the air. The children proposed that light objects that contained air were more likely to float and that items such as the sponge ball because of its properties were more likely to float. When

asked to devise an approach to testing the materials the children agreed that they would put them all in water and observe how the objects behaved. It was at this point that the children entered into an active debate about what they would look for in order to assess whether an object was sinking. This debate was captured in the transcript extract Table 79 (Figures 60, 61 and 63) and showed how the children used both their verbal discussions and gesture representations in order to reach agreement about object position and motion.



*Figure 60: Sarah and Daniel's representational gestures used as they negotiate as a group how floating and sinking will be defined (Table 79).*



*Figure 61: Daniel uses the water tank as a prop in his discussions of where objects should be located in order to be considered either as floating or sinking.*

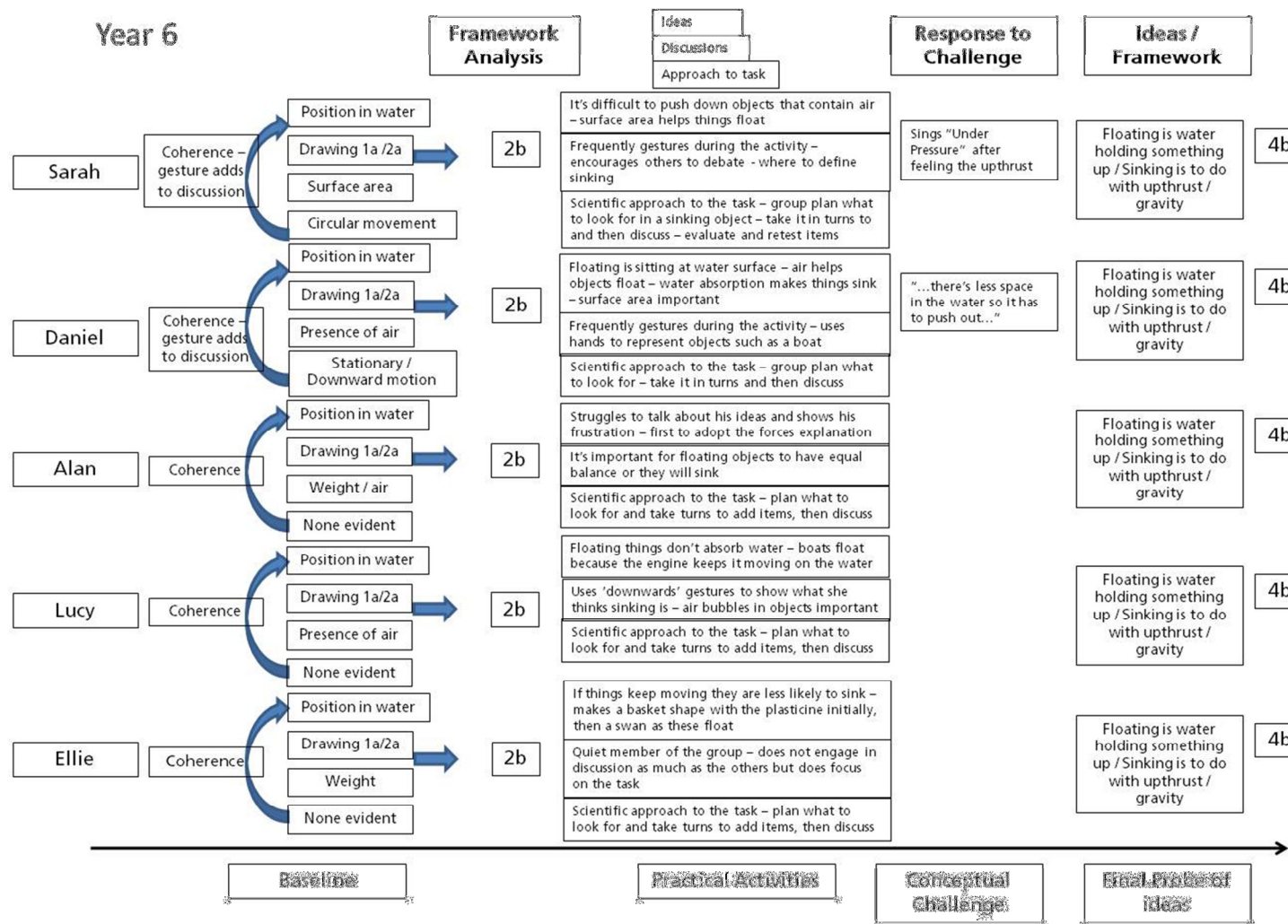


Figure 62: Year 6 Floating and Sinking Group Study Storyboard Analysis.

Time	Person	Verbal Report	Gesture	Other Non-verbal
14:25	Sarah	<p>Yes, because it has to touch the bottom of the water for it to actually sink...</p> <p>Cuz if it's just like floating above then it is still floating...</p> <p>Not just right at the top.</p>	<p>Sarah uses her right index finger to make a downwards motion that ends when her fingertip touches the table top.</p> <p>Uses both of her hands to make slight side to side rocking motions.</p> <p>Moves her hand in a vertical motion with her left hand moving towards the table and her right hand moving upwards.</p>	
	Daniel	It's sort of like.		
	Sarah	If something sinks then it goes down to the bottom.	Sarah uses her right hand to make a fluid motion in which the hand moves in a downward motion.	
	Daniel	If it like.	Tries to mime what he means but is struggling to show it.	
	RS	I tell you what shall I move the tank over her so that you can show me?		
	Daniel	Yeah.		
	RS			Moves the water tank to the table.
	Daniel	So if it's like there then it's sunk, if it's there it's floating.	Uses a 2p coin to show locations in the water tank, hold the 2p coin at the base of the tank when he	

			say “sunk” then moves the 2p coin to the top of the tank when he says “floating”.	
	Daniel	Say if this is a boat it’s kind of sunk there, look if the boat’s there it’s kind of sunk innit.	Daniel holds the 2p coin about an inch above the bottom of the water tank so that the others in the group can see where he is holding it	Lucy and Ellie nod in agreement.
	Lucy	Completely under the water.	Lucy uses her hands to indicate a downwards motion.	
	Daniel	Completely.		

*Table 79: Transcript extract showing the interaction between the group as they develop their ideas about the criteria that an object would need to meet in order to be either floating or sinking (RS = researcher).*

Once the children had agreed on what an object must do in order to be considered sinking they then went on to test the objects and observed their behaviour. The children systematically added the items one at a time and discussed what happened. Once they had completed this action with all of the objects they then decided that watching the speed with which an object sank could be used in order to assess the weight of the object. The children planned an approach to testing two of the metal blocks in order to assess their weight. The approach taken was considered particularly scientific and was assessed according to the outcome. When the researcher moved the discussion on the children expressed their surprise that the different types of wood behaved differently in the water (e.g. the snake wood sank whilst the hard and softwood blocks floated). When probed for why they thought this happened Sarah stated that she thought that the snake wood was more solid and Lucy stated that she thought that the other wood contained more air bubbles. Overall

the children showed a high level of accuracy in their predictions with the exception of the snake wood.

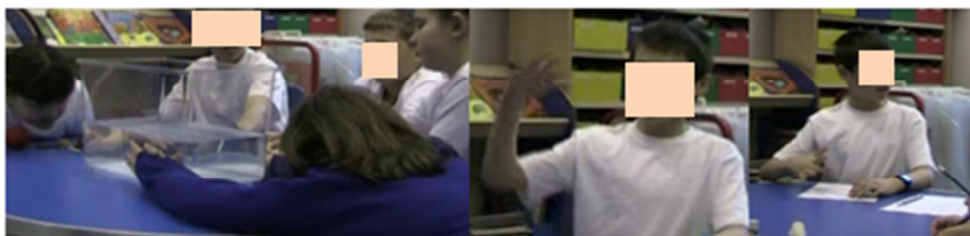
When challenged to make the plasticine float the children tried a range of different shapes including a star, a swan and a shallow bowl shape. Once a shape that floated was achieved (the shallow bowl shape) the children began to add marbles to the model, all of the children agreed that it was important for the model to have 'balance' in order to keep it afloat.

Overall, this group of children demonstrated extensive use of gestures in all five categories, some example are presented here. In the first example shown in Table 80 (Figure 63) Daniel can be observed using two forms of gesture. Firstly he used a representational gesture in order to demonstrate his understanding of what he thought sinking was. This gesture is interpreted as adding to Daniel's verbal discussion and appeared to demonstrate how he thought a sinking object would move through the water. At the same time Daniel used a social gesture in which he looked to Alan. It appeared that Alan interpreted this social gesture as a question and he verbally responded to this by saying that he 'can't remember' before placing his head down onto the top of the table.

Time	Person	Verbal Report	Gesture	Other Non-Verbal
05:32	Daniel	If it has water in it's more likely to sink.	Daniel begins the gesture with his right hand level with his shoulder and moves this in a diagonal downwards motion which stops at the table top.	Looks to Alan as he does this.
	Alan	I can't remember.		Alan places his head on

				the table.
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*Table 80: Transcript extract showing social gestures used between Daniel and Alan during the floating and sinking activity.*



*Figure 63: Daniel using the tank as a reference point for his ideas about floating and sinking (Table 79) and Daniel's representational gesture, used to show how he thought an object would behave when sinking and Daniel's social gesture to Alan (Table 80).*

In another example, Daniel was observed using a thinking gesture as he worked through his ideas. Daniel began to move his hand towards his face. At the same time Daniel uses another social gesture, and he looked towards Lucy as she began to speak (Table 81).

Time	Person	Verbal Report	Gesture	Other Non-Verbal
00:46	RS	Ok, is it always because it doesn't have air in it?	Daniel begins to shake his head.	Lucy puts her hand up.
	Daniel	Well no.	Daniel his left hand to his face.	Looks to Lucy as she begins to speak.

*Table 81: Transcript extract showing the social gestures that occur between Daniel and Lucy during the floating and sinking activities (RS = researcher).*

In response to the conceptual challenge aspect of the task all of the children agreed that water displacement, upthrust and gravity may have a role in helping objects to float. Interestingly, Sarah began to sing the Queen song '*Under Pressure*' as she pushed the balloon into the water. This choice of song appeared to link to her understanding of the force that she was able to feel on the balloon. Once Sarah

begin to sing the whole group began to join in and for a few moments all of the children are singing “...pressure pushing down on me, pushing down on you...” Whilst it is difficult to be certain, this song did appear to play a role in not only bringing the group together but also in facilitating this group’s understanding of the phenomena under observation. This group did show evidence of conceptual change by the end of the activity. When probed for their ideas about floating and sinking, they all proposed that this was related to forces. Floating was redefined as the water holding the object up and sinking was redefined as being ‘something to do with upthrust and gravity’. At the end of the activity the children’s ideas were categorised as 4b, this framework acknowledges that the children have now incorporated knowledge of forces into their discussions (section 7.2.4 has further details on the frameworks associated with floating and sinking). It was for this reason that this particular group study was used for the later timeline analysis which explored the development of ideas over the course of the activity (section 7.4).

### **7.3.5 Year 9 Group Study**

The Year 9 group study focuses on three children (one female, two males) called Nigel, Nick and Kirsty from Village Secondary School. This group study lasted approximately 40 minutes from the beginning to the end. The activity was held in a vacant science laboratory within the school. Throughout the activity one secondary school science teacher remained in the room in order to observe and comply with the insurance specifications of teaching in this environment. The group was randomly generated by the researcher who formed the group by drawing names from the consent forms provided by the participating children. The researcher had no prior knowledge of the children’s academic ability prior to forming the group but it was proposed by the class teacher that the children in this class were of mixed academic ability. The group study is summarised in the storyboard contained in Figure 64.

Overall this particular group of children worked well together but they tended to be quieter during the activity than the younger children (Year 2 and Year 6). They did discuss their ideas and sometimes offered support to each other during the activity



but this was not in any way close to the scale that was observed within the Year 6 group study.

As with the other groups at the beginning of the activity the Year 9 children produced drawings that featured two objects: one in the floating position and one in the sinking position. The floating item was drawn at the surface of the water and the sinking object was drawn at the bottom of the tank. These drawings appear to support the previous results in which the other groups of children appeared to represent a dichotomous relationship between floating and sinking. Interestingly two of the children, Nick and Kirsty drew two circular shapes, one in each position. In both instances these circular shapes were identical in size, although it was difficult to definitively state why this occurred it appeared to show that these children were aware that objects that look identical can appear in both of these positions. This may reveal that they understood that underlying, not necessarily observable differences, can influence whether an item floats or sinks. Nigel drew a boat in the floating position and a brick shape in the sinking position. This choice of objects appeared to represent his previous experiences and when probed he said that he had seen these object do this before.

All three children in this group provided written responses to the sentence completion tasks:

*The object is either light or hollow and the water resistance keeps it up. (Nick)*

*They have air inside and it makes them lighter. (Kirsty)*

*They have air in them or something that is lighter than the liquid. (Nigel)*

Overall these responses appeared to show that the children have a number of ideas for what makes an object float with the weight of the object still appearing one of the most important factors. Nick did introduce the idea of water resistance in his written response and Nigel appeared to represent the idea of a relationship between the weight of the object in relation to the water.

When asked to complete the sentence objects sink because, the following responses were produced:

*The object is heavy and / or not hollow. (Nick)*

*They are solid which means they are heavier. (Kirsty)*

*They don't have air in them or something heavier than the liquid. (Nigel)*

As with the responses to the floating question, the children appeared to demonstrate a range of responses that covered the number of different ideas. Some of the responses appeared to attend to the weight of the objects. Nick appeared to discuss the internal properties of the object (e.g. whether it is hollow) and Kirsty discussed objects being solid. It is proposed that these two explanations actually reflect the same idea (e.g. that objects which are not solid or have internal hollow spaces are more likely to float). Once again Nigel appeared to acknowledge a relationship between the weight of the object in relation to the water.

In the children's verbal responses, however, they all appeared to pay attention almost exclusively to the object properties (e.g. they stated that heavy things would sink and light things would float). When probed on these ideas the children also identified that objects were more likely to float if they were full of air or were hollow. In their gestures produced at the beginning of the activity, both Nigel and Nick appeared to use these to represent the behaviour of the object in the water. In the first example (Table 82; Figure 65) Nigel used his index finger to represent how an object would move through the water if it were to sink. Nigel's gesture was particularly useful for revealing how he thought an object would move if it were to sink even though at this stage in the activity he was discussing what he thinks floating is. This use of a representational gesture appeared to reflect the dichotomous relationship that he thought existed between floating and sinking (e.g. that one is the opposite of the other and indeed one representation can be used in order to provide clarity on what the other is).

Time	Person	Verbal Report	Gesture
00:43	Nigel	Something that if you put it in water doesn't go to the bottom.	As he speaks Nigel uses the index finger on his right hand to point downwards towards the table, he then uses this to make a slight downwards motion.

*Table 82: Transcript extract showing Nigel using a referential gesture during his discussion of what floating is.*

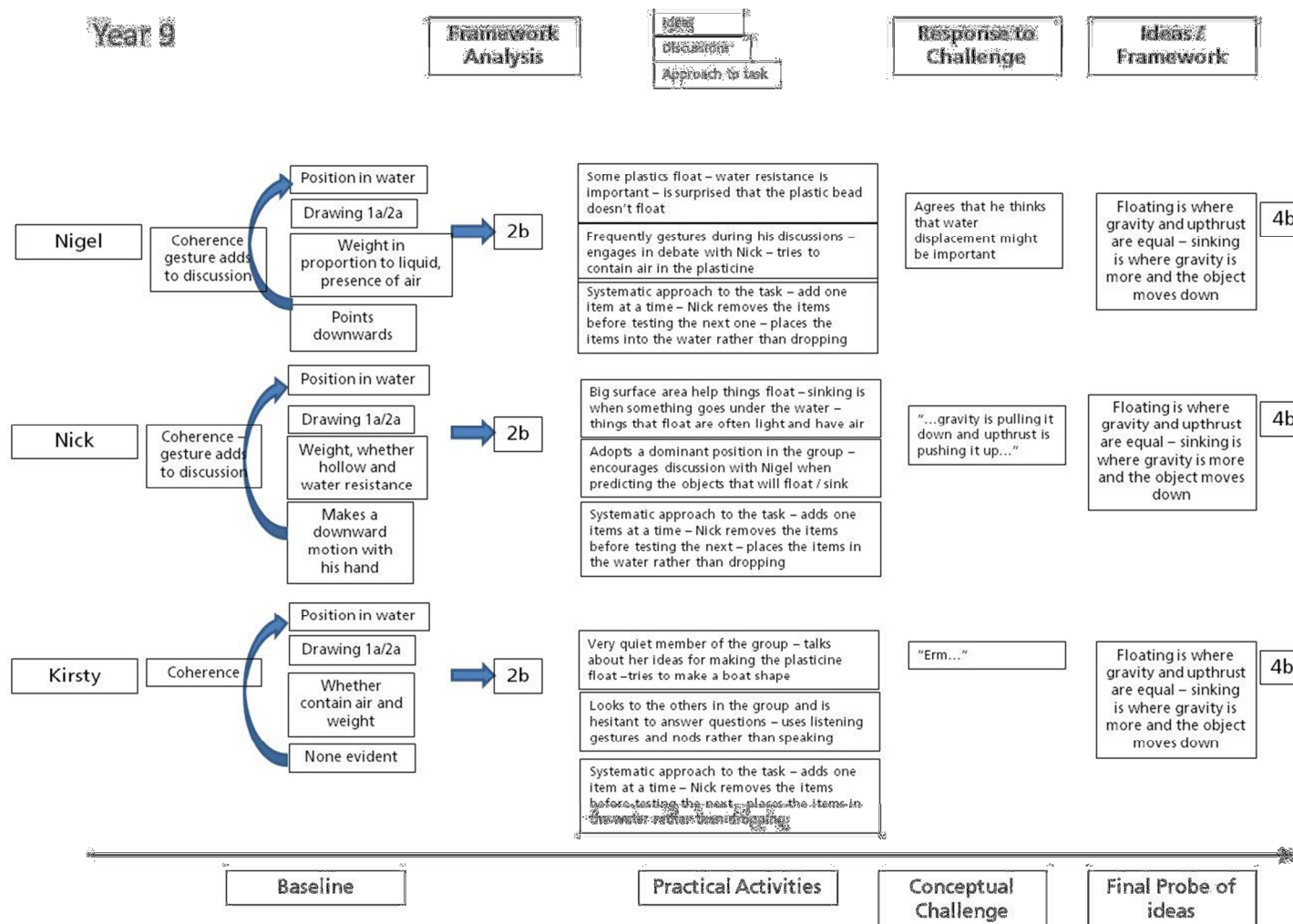


Figure 64: Year 9 Floating and Sinking Group Study Storyboard Analysis.



*Figure 65: Nigel's representational gesture (Table 82), Nick's representational gesture (Table 83) and Nick handling an object as discussed his ideas for items that float and sink (Table 84).*

Nick also used gestures in order to extend his verbal discussion. In this example Nick identified what he thought sinking was (Table 83; Figure 65). Nick produced a downward motion that began at his shoulder and ended at the surface of the table. One interpretation is that this representational gesture showed the way that he thought that the object would move in the water is if were to sink. This gesture added to Nick's verbal discussion.

Time	Person	Verbal Report	Gesture
00:41	Nick	Is it like, it goes under the surface of the water.	As he says this Nick uses his right hand to make a downward motion which starts at his shoulder and end at the top of the table.

*Table 83: Transcript extract showing Nick using a representational gesture during his discussion of what he thought sinking was.*

Overall, the group was categorised as having a 2b framework for their floating and sinking ideas. The 2b framework, as identified in section 7.2.4, focused on the properties of the object and although in the children's written responses there is some evidence of awareness of other factors, such as the properties of the liquid in relation to the object, these ideas are not applied consistently across the response types.

When asked to complete the material sorting task, the children showed a high level of accuracy in their predictions. When asked for their rationale for the groups that they had created the children proposed that the items on the float pile were there because they were light and they contained air holes. As this discussion emerged Nick picked up the red sponge ball which he handled as he talked and placed it back on the table only once he had finished talking. This use of the object to support the discussion was interesting and it appeared that Nick was using this object as an example in order to illustrate what he meant (Table 84; Figure 65).

Time	Person	Verbal Report	Gesture
06:18	Nick	Well most of them are quite light and they have got well you can't see if but they have got air holes.	As Nick says quite light he picks up the red sponge ball moves it around his hand and then lowers it to the top of the table.

*Table 84: Transcript extract showing how Nick anchors his discussion of weight to a physical object during his discussion of what he thinks makes an object float.*

A similar gestural response was used as the group discussed the items that they had placed in their 'don't know' pile. The children proposed that they were uncertain about some items because of their properties (e.g. the clear plastic disk is placed on this pile). When probed for their ideas, Nick proposed that the disk was not that heavy and it had a fairly big surface area. But they were uncertain as to what it would do. In this example, once again Nick picked up the object as he spoke, he moved the object around in his hand and then placed it back down as he completed his discussion. It could be that the object was used in this way to reduce possible misunderstandings or that by picking up the object of reference the child was able to reduce the need to identify the object as he was talking. Indeed in this example Nick never actually identified the object that he was discussing instead he just picked it up from the table as he spoke (Table 85; Figure 66).

Time	Person	Verbal Report	Gesture
07:18	Nick	Well it's like for this one [the clear round plastic disk] it's not like heavy but it's got like a bigish surface area which might help it to float because it's spread out.	As he says this one he picks up the clear plastic disk, rotates it between the fingers of his left hand and then puts it back down on the top of the table.

*Table 85: Transcript extract showing Nick anchoring his discussion to objects.*

Interestingly, it was at this stage that the children were also drawing on their previous experiences in order to make their decisions. At one point, Nigel proposed that he is unsure about an object because he couldn't remember what it would do. When probed for their ideas about the items that they had classified as sinking the children proposed that most of them were heavy, solid and had 'no gaps' in them. When probed further for what they meant by having 'no gaps' Nick began to draw on a new concept, the particle placement within the material, in order to complete his discussion. When asked to plan an approach for testing the objects the children adopted a systematic approach to the task. They agreed that all of the items should be placed in the water and that they should observe the behaviour of the object in order to assess whether it floats or sinks. Nigel proposed that they should just put the items in. The children took it in turn to add items to the tank. However, they were all careful to place the items in the water rather than to throw them in. Nick removed each item after it had been tested and the items were placed on different towels depending on what happened. When probed for their responses to the behaviour of some of the objects, Nick expressed surprise that the snake wood sank. Again he did not clearly identify the material but instead he held this up so that the researcher could see it before putting it back down on the table (Table 86; Figure 66).

Time	Person	Verbal Report	Gesture
12:53	RS	So can I ask you about those materials then? Was there anything there that surprised you?	
	Nick	I wasn't sure about this one [the snake wood] because it was quite light so I thought it might float but obviously not.	As he says this Nick picks up the thin piece of snake wood, holds it up to show the RS and

			then lowers it back down to the towel.
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*Table 86: Transcript extract showing Nick's surprise about a piece of snake wood that sank during the problem solving activity.*



*Figure 66: Nick holds up an object that he is discussing (Table 85), Nick holds the piece of snake wood during his discussion of things that surprised him (Table 86) and Nigel hold the bead in his hands that surprised him during the object testing phase (Table 87).*

As with the younger children (Year 2 and Year 6) and as previously discussed in the examples related to Nick, these children also frequently handled the objects as they discussed them. Often the objects were rotated between the participants' fingers or held in outstretched hands. Another example of this kind of object manipulation is shown in Table 87 (Figure 66). In this example Nigel is discussing an object that surprised him because it sank when he thought that it would float. In his verbal response, it was not clear which object he is referring to, however, by picking up the object Nigel's discussion was completed and it is possible to understand which object has surprised him. It was also interesting to watch the way that he manipulated the object, as he talked Nigel rotated the object between his fingers and inspected it thoroughly as though looking for evidence to support why this had occurred.

Time	Person	Verbal Report	Gesture
13:33	Nigel	This sort of surprised me because of the volume but it does have a hole in the middle...the air ...	Nigel reaches forward and picks up the plastic bead from the towel in front in Nick, he holds the bead between his thumb and forefinger and rotates it as he speaks once he finishes speaking he puts it back down onto the towel.

*Table 87: Transcript extract showing Nigel anchoring his discussion of items that surprised him during the problem solving activity to the actual objects.*

When challenged to mould the plasticine in order to make it float, all of the children tried a range of different shapes. Nigel formed a boat shape because he knew that boats float. Nick made the plasticine as thin as he could because he thought that by making the surface area bigger it should work, whilst Kirsty tried to make the plasticine 'lighter' by spreading it out. Nick was the first child to make his plasticine float, he formed a boat shape with high sides. The children were then challenged to add marbles to the shape. They all agreed that the marbles needed to be evenly distributed in order for the shape to still float. This model making activity demonstrated the children's awareness of a range of factors related to items that float, which they then applied during the task. For these children it was clear that they showed an understanding that the surface area of the object can enhance its ability to float and that the distribution of weight is also important for a floating object.

When challenged through the balloon activity all of the children were easily able to accept the concepts introduced. Nigel agreed that he thought that water displacement was important for helping objects to float. Nick demonstrated a good understanding of the influence that gravity had and related this to the upthrust force pushing up. When probed for their ideas at the end of the activity, this group also demonstrated evidence of conceptual change. They proposed that floating occurred when the gravity and upthrust forces on the object were equal, whilst sinking was considered to occur when the force of gravity on the object was greater thus the



object moved down in the water. At the end of the activity the group are categorised as holding a 4b framework (see section 7.2.4 for full details of the different frameworks) for their ideas of floating and sinking, this framework acknowledges that the children have an understanding of the role that forces play in floating and sinking.

#### **7.4 Mapping Conceptual Change across a Floating and Sinking Activity**

In order to explore in more detail the way that the children's ideas can change within the context of one floating and sinking practical science activity a timeline analysis was conducted on the Year 6 group study data (Figure 67 provides an overview of the development of the children's ideas during this activity).

The Year 6 activity detailed in the timeline for the development of ideas above demonstrated the following developmental pattern for the concepts used and discussed throughout the activity. During the first probe of the children's ideas for floating and sinking Daniel introduced the first single concept, this focused on the position of the object in the water. This single conceptual idea was extended by Daniel to a network of two ideas when he proposed that the presence of air in the object was important and influenced the position of the object in the water. Lucy subsequently revised Daniel's ideas and incorporated the inclusion of weight, thus developing the network further to now include three ideas. Finally during the beginning of the activity to the 2 minute timeslot the network was extended one final time by Sarah. Sarah proposed that surface area was also an important factor that was related to floating and sinking. Thus during the initial probes of children's ideas a weak form of conceptual development appeared to occur as the children progressively incorporated new ideas into the network. The core idea, which was the position of the object in the water, did not change but additional information was added to this as it developed.

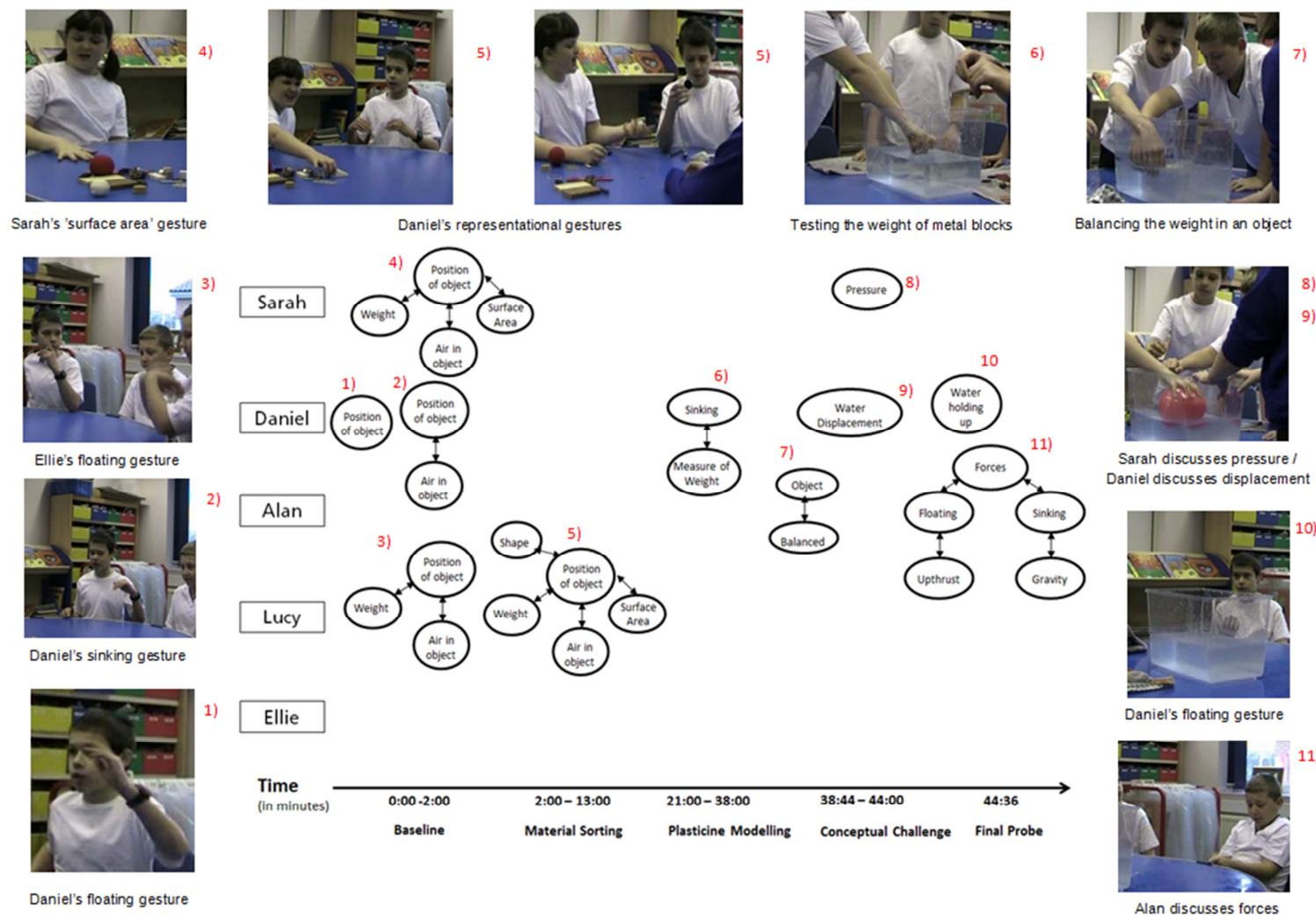


Figure 67: A timeline analysis of the Year 6 Floating and Sinking activity.

As the activities moved on the network of four ideas continued to be applied by all of the children until they reach the 11 minute mark (shown within the timeline as the 2:00 – 13:00 minute period), at this point Lucy introduced another new concept to the network of ideas. Lucy proposed that the shape of the object was important. The core concept in the network, the position of the object in the water, remained the same and the new idea is added to the network. These findings showed evidence of the increasing complexity of the network of ideas that was revealed as children moved through the activities, by adding different tasks such as material sorting the children were able to incorporate these new elements into their existing understanding.

During the time between 21:00 minutes and 38:00 minutes, which was the time that the children were discussing the behaviour of materials during the testing phase and the modelling of the plasticine in order to make it float a new network of ideas was revealed. Daniel proposed that the sinking concept could be used as a way to measure the weight of an object. What was interesting was that this network revealed Daniel's understanding that weight was an important factor in the floating and sinking activity and that such activities could be used in order to test other factors.

During the conceptual challenge aspect of the task a number of new networks of ideas are revealed. Firstly, Alan identified that in order to make objects float they must be balanced. This small network of ideas appeared to sit in isolation and was none the less an important aspect of Alan's thinking regarding floating and sinking and indeed revealed an important aspect regarding the way that his ideas were developing. When attending to the demonstration of water displacement using the balloon Daniel acknowledged this as an isolated concept and began to incorporate this idea into his own discussions. When testing the way that the balloon felt when it was pushed down into the water Sarah associated the upthrust force with "pressure" and as before this idea appeared to sit as an isolated concept at this point in the activity. Interestingly though by the end of the activity the concept of pressure appeared to be transformed by Daniel who now proposed that in fact this was the water holding the object up. This network containing just one idea was further adapted into a complex network by Alan. At the very end of the activity Alan showed evidence of a clear revision of the network of ideas presented thus far, Alan replaced

the core concept in the network with the idea of forces and indeed this was the term that he used, he then associated floating and sinking with the forces of upthrust and gravity. This network of five ideas showed a complete revision of ideas from the beginning of the activity to the end thus demonstrating evidence of radical conceptual change.

This particular group study was interesting for two reasons. Firstly throughout the activity it is possible to witness a weak form of conceptual change occurring as the children added new information to the ideas that they already had. In addition, it was possible to observe a radical form of conceptual change between the beginning and the end of the activity, as the core concept for the network was changed from being the position of the object in the water to being the forces involved in the floating and sinking process.

## **7.5 General Discussion**

Overall, the results of the traditional analysis of children's ideas for floating and sinking indicated that these ideas do become more scientific over time with the older children typically discussing more complex concepts than the younger. In terms of the drawing completion tasks, the results revealed that the older children were more likely to produce identical objects in both the floating and sinking positions, potentially indicating their understanding that the internal properties of objects were more important. The younger children typically drew ducks, boats and people as floating objects, and rocks, bricks or stones as sinking objects. These drawings may reflect the children's everyday experiences of floating and sinking objects. As with the electricity activities, the oldest children always presented completed sentences whilst the younger children's responses were more variable. However, all children readily responded to the verbal probes and, as anticipated, the results highlighted that the older children were more likely to use a range of reasons to explain floating and sinking whilst the youngest children tended to discuss weight.

Interestingly, the results of the conceptual challenge aspect of the tasks highlighted that the older children were more likely to revise their ideas once they were challenged through the tasks and, as with the electricity activities the children

frequently incorporated the new terms such as upthrust into their discussions. There was some evidence of both weak and radical changes in the concepts used. Importantly, as with electricity, although the youngest children (Year 2) had been able to discuss the complex concepts of upthrust and water displacement during the conceptual challenge task, none of these children incorporated this into their ideas at the end of the activities. The results to the traditional analyses as a whole appear consistent with the previous research finding of Inhelder and Piaget (1958), Howe, et al. (1990) and Havu-Nuutinen (2005).

The results of the multimodal analyses provided further support for the importance of exploring this range of response types. The gestures that the children used during the floating and sinking activity could be sorted according to the categories defined during the pilot studies. However, the prevalence of these gestures did appear to be mediated by the scientific topic studied. Notably, referential gestures were far more common during the electricity activities. This may in part be explained by the theoretical nature of the topic or perhaps it was because the children frequently held and manipulated objects during the floating and sinking activity and this object manipulation may have replaced the pointing gestures used with electricity. What was evident was the finding that again the gestures that the children used during floating and sinking did indeed appear to play a fundamental role in providing more information about the children's ideas themselves. In order to explore this further, a selection of group studies were subjected to a full multimodal analysis using the storyboarding approach in order to uncover more detail about the children's ideas across the age groups. The results revealed that the children used the full range of response types to support their articulation of the ideas about floating and sinking. These group studies and in particular, the Year 6 group study, also showed the importance of the social context during learning with the children frequently working together in order to produce more advanced concepts throughout. The Year 6 group study was also subjected to further analysis in order to explore the evolution of concepts during a single activity. As shown in Section 7.4, this analysis revealed an increasing complexity of networks of ideas produced, notably, showing both weak and radical forms of conceptual change.

## Chapter 8 Summary and Conclusions

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### 8.1 Introduction

In this concluding chapter, the work in this thesis is reviewed and critically evaluated both against the research literature introduced earlier and on its own terms. In particular, this chapter considers the importance of the multimodal approach adopted here and reflects on the ways that this might be used to inform general constructivism (as discussed in Chapter 2), what additional information such an approach may reveal about children's ideas in science, the mechanisms underpinning models of conceptual change (as discussed in Chapter 3) and the ways that children's ideas about electricity and floating and sinking change over time (as discussed in Chapters 6 and 7). As previously identified in the development of methodology (Chapters 4 and 5), a multimodal approach suggests that communication occurs across a range of response types (Kress, et al., 2001). These response types include verbal and written communication, drawings and non-verbal communication such as body language and gesture (Kress, et al., 2001). Multimodality in relation to understanding how knowledge is acquired and discussed is a new and evolving field of research but is beginning to be applied to science education and science education research. The work in this thesis makes an original contribution towards and builds upon this early foundation. In addition, this chapter also provides a focused discussion about the four models of conceptual change that have been utilised during this work in order to show how these have been used to inform the analytical lenses applied, what each model brings to the discussion and how each can be interpreted in a new hybrid model of conceptual change. Finally in this chapter, the research undertaken is also considered briefly for its wider application to science teaching and learning in order to explore what may be drawn out to support science teachers.

This work was given focus and direction by raising the following research questions:

- does a multimodal analysis of verbal and non-verbal communication facilitate a better understanding of children's ideas in science?

- can such analyses be utilised in order to explore and contribute to an understanding of the dynamics of conceptual change?
- do outcomes from the work in this thesis have any classroom application?

An overarching question regarding whether or not it is possible to apply a multimodal research lens to the issues of conceptual change in science education is also proposed. Each of these questions is responded to in the subsequent sections of this chapter. In summary, and as a whole, the work in this thesis might best be considered to have multiple method design incorporating a multimodal, task-based approach for which a new and innovative methodology was developed. Three Research Phases were highlighted in Chapter 4 with the main data collection taking place in Research Phase 2. Participants in Research Phase 2 included 93 children aged between 6 and 14 years in Years 2, 6 and 9 in four schools in the East Midlands. The science topics explored included electricity and floating and sinking, both common across the National Curriculum, and chosen because both had been previously studied in the conceptual change literature (e.g. for electricity see Shipstone, 1985; Osborne et al, 1991; Borges & Gilbert, 1999, for floating and sinking see Inhelder & Piaget, 1958; Howe et al, 1990; Havu-Nuutinen, 2005). Electricity as taught in school is often conceptually driven and counter-intuitive and relies on children's abilities to interpret phenomena that are not always directly observable. Floating and sinking, on the other hand, was chosen as this provides children with the opportunity to explore a topic that they may have encountered many times before in a concrete way with resources that could be directly manipulated.

The multimodal, task-based approach developed for this study incorporated dialogic teaching (Alexander, 2004; Fisher, 2007; Mercer et al, 2009; Heneda & Wells, 2010) with carefully developed practical science activities embedded and utilising collaborative learning opportunities (Howe, 2009). The tuition was delivered by the researcher as a participant. The main stage of the research generated 72 hours of audio-video materials and drawings and written responses which required extensive transcription and analysis. This required the design and development of an NVivo project to facilitate the analysis of gesture and other classroom interactions including

where learning took place. The quality and quantity of data and other materials collected required the introduction of 'storyboarding'. Whilst popular in media and in business studies, this has never, as far as is known, been used in a science education context before. Finally, in order to capture what, if anything, changed in the children's ideas during the science tasks and activities, a form of timeline analysis developed from the work of Givry and Tiberghien (2012) was incorporated to map the evolution of children's ideas in 'real time'.

This work, including its design, methodology and analytical tools developed and employed, is believed to be the first of its kind in the UK and in this context. In part, this is due to the significant amount of data analysis that is necessary in order to successfully undertake a multimodal analysis so that an appropriate level of detail can be captured.

## **8.2 Research Question 1: Does a multimodal analysis of verbal and non-verbal communication facilitate a better understanding of children's ideas in science?**

In order to explore whether or not the multimodal analysis of verbal and non-verbal communication facilitates a better understanding of children's ideas in science this section explores both the traditional and a multimodal analyses adopted. The 'typical' traditional approach to studying children's ideas is contrasted and critiqued using the novel multimodal approach developed in this thesis, with the specific aim of highlighting its utility.

### **8.2.1 A 'Traditional' Approach to Studying Children's Ideas**

As detailed in Chapter 4, the traditional constructivist approach to studying children's ideas frequently employ research interviews (e.g. Vosnidaou & Brewer, 1987), often including children's drawings (e.g. Sharp & Kuerbis, 2006), science tasks (e.g. Biddulph & Osborne, 1984), and observational details (e.g. Tasker, 1981). The content from these is then analysed for the underlying ideas or frameworks presented and subsequently used to compare what ideas children have (see



Chapter 4 for a full review of traditional constructivist approach to studying children's ideas). This approach has proved to have high validity and reliability in the science education field. These traditional approaches provided the foundation for the new and innovative multimodal approach developed for this work. However, it is important to address the weaknesses of this approach, for example, the influence that questioning strategies can have on children's responses (Mathison, 1988; Lythcott & Duschl, 1990), the difficulty that some children can have when representing their ideas in drawings (Symington, et al., 1981; Cox, 1992) and the challenges of accurately interpreting children's responses when working from an adult's frame of references (Johnson & Gott, 1996).

### **8.2.2 Electricity**

The research literature regarding children's ideas about electricity was discussed in Chapter 3 and included three important studies that had been highlighted for their comparative value (Shipstone, 1985; Osborne et al, 1991; and Borges & Gilbert, 1999). The results to the traditional approach to analysis undertaken in this thesis are compared with these studies here both thematically and by framework. The analysis of the themes was guided by diSessa's model of conceptual change (1988), which highlighted the importance of assessing the way that pieces of information (p-prims) are related to each other. The results of the electricity activities that were undertaken as a part of Research Phase 2 of this work revealed a number of interesting themes in the children's responses to what they thought electricity was both before and after tuition (Table 18). The Year 2 children frequently discussed electricity according to its purpose (e.g. that it makes things work or that it was a form of power). By Year 6, the children were progressing to think about electricity in terms of what it actually is rather than what it does (e.g. a flow of electrons). The Year 9 children ideas were more diverse, eventually thinking about electricity in terms of energy and electrons. With the exception of Year 2, the children ideas evolved to become more scientific as they got older. These results suggested that for these children the conceptual challenge task was particularly helpful for supporting the children in the development their ideas.

In order to explore the overall frameworks of understanding that the children held about electricity, a framework analysis which was underpinned by the work of Vosniadou was conducted on the children's responses before and after the activities (Table 19). The results revealed that the youngest held unipolar and clashing currents models initially. The most frequently occurring model among Year 6 and Year 9 children was the closed circuit variety. Following conceptual challenge, however, more scientific models were evident throughout.

As with the previous studies of Shipstone (1985), Osborne, et al. (1991) and Borges and Gilbert (1999), one important finding was that the children did appear to use different frameworks of understanding depending on the nature of the questions asked and the task to be completed. For example, in the discussion in Chapter 6 it is highlighted that when the circuit building activities required the children add additional bulbs they were more likely to introduce what appeared to be a 'clashing currents' model in order to explain how electricity 'flowed' through the circuit to both bulbs. This particular finding highlighted potential issues related to reliability and validity and it was particularly difficult to locate some of the children's ideas in a specific framework. Thus the results presented are reviewed with a caveat that in some cases the children appeared to frequently revise or review their ideas about electricity. None of the four additional frameworks identified by Borges and Gilbert (1999) were evident in this sample of participants, perhaps indicating that the new frameworks are relevant to more advanced age groups rather than school children.

Furthermore, as highlighted by the previous research of Osborne, et al. (1991) this study found that the younger children typically discussed electricity in terms of its purpose, whilst the older children demonstrated more sophisticated scientific explanation in their ideas and discussed 'current', 'atoms' and a 'flow of electrons'. These results were consistent with those proposed by Shipstone (1985) who also highlighted the move towards more advanced models in the older children. Returning to the results to the SPACE project this study also found that the younger children were less able to identify what conductivity was, less able to judge the materials that would be able to conduct electricity and less able to generate an appropriate method for the testing materials. These results were not found in the older children who were able to accurately sort materials according to these properties and effectively test them for their behaviour.

Further interesting results were related to the children's use of language, as anticipated the oldest children (Year 9) used the most scientific terms in their discussions whilst the youngest children (Year 2) tended to use everyday terms such as 'electricity makes things work'. The Year 6 children showed more variable results in terms of the language that they used and the ways that they defined electricity.

### **8.2.3 Floating and Sinking**

The research literature exploring children's learning about floating and sinking was discussed in Chapter 3, as highlighted three important papers are considered for their comparative value (Inhelder & Piaget, 1958; Howe, et al., 1991; Havu-Nuutinen, 2005). As with the previous section, three of the selected models of conceptual change as also considered in their critical review of results.

Using diSessa's (1988) analytical approach the results of the floating and sinking activities that were also undertaken as part of Research Phase 2 of this work revealed a number of interesting themes in the children's responses about what they thought was meant by the terms floating and sinking (Tables 55 and 56). The Year 2 children frequently discussed floating and sinking in terms of an object's location in the water. By Year 6, the children were progressing to think about floating and sinking in terms of not just location of the object in the water but also in terms of the weight of the object and forces such as gravity. The Year 9 children's ideas included further important scientific aspects such as water displacement. With the exception of Year 2, the children's ideas evolved and became more scientific after undertaking the conceptual challenge task. These results suggested that for older children this task was particularly helpful for developing ideas.

In order to explore the underlying frameworks in the children's ideas these were assessed both at the beginning and the end of the tasks. The analytical framework was informed by Vosniadou's work (Vosniadou & Brewer, 1987). The results of this analysis are summarised in Table 57. The results revealed that the younger children, Year 2, typically focused on the properties of the object. For the older children (Year 6 and Year 9) there was a greater amount of variability in the results for the

frameworks held with some Year 6 children focusing on object properties whilst others discussed forces, after conceptual challenge many of the Year 6 children discussed forces. Similarly, some Year 9 children focused on the properties of the object at the beginning activities, some discussed forces and some children used combination frameworks which incorporated aspects related to both the object and the liquid. Following the conceptual challenge activity none of the Year 9 children focused exclusively on the properties of the object, instead the children used the forces framework or a combination framework which accounted for both properties related the object and those related to the liquid.

Overall, these results were largely consistent with the previous research of Inhelder and Piaget (1958), Howe, et al. (1990) and Havu-Nuutinen (2005) with the younger children typically focused on the properties of the object. By comparison with previous research, the results supported the studies of Inhelder and Piaget (1958) and the study by Howe, et al. (1990). The ideas that the children presented became more scientific over time and moved away from focusing on the properties of the object in the water, to discussions that included an awareness of the properties of the liquid and an understanding of 'global' aspects such as forces. As previously mentioned, this was perhaps the first study to take into account a forces framework and therefore provided a new layer of understanding for what children know about floating and sinking, particularly with reference to these more 'global' aspects. One criticism of the previous research has been its emphasis on the concepts of density and children's understanding of the way that the density of both the object and liquid can influence whether or not an object will float or sink. In terms of concepts related to floating and sinking, it is perhaps less straight forward than it first appears and there are many factors that can play a role. This level of complexity is often not reflected in the literature. In terms of the results of this current work, however, it is clear that there are aspects of the findings that can easily be reconciled with the previous research. Children's ideas about floating and sinking do, in the early stages at least, appear to take an object centred view and it is only as children get older, and perhaps engage more with tuition about floating and sinking, that they become aware of the important role that other factors play.

### **8.2.4 Limitations of the Traditional Analysis**

As with any research project it is important to consider the limitations of the work discussed here. These include the convergence of findings due to methodology, issues of matching ages in the studies, the difficulty of the concepts explored, and the children's previous experiences with the topics. In terms of methodology, this work, like many previous studies exploring children's ideas from a constructivist perspective, utilised a multiple method approach in order to provide methodological triangulation (Cohen, et al., 2011). Furthermore the need for multiple method studies is highlighted by Johnson and Gott (1996). Johnson and Gott's important work introduced an important criticism of adults' work with children and the possibility that misinterpretations of data can occur. Because of this, methodological triangulation was perceived to be of fundamental importance. As has been discussed, it was clear that by adopting a combination of methods, which included children's drawing, interviews and science tasks, it was possible to reveal findings that largely converged with previous studies in both electricity (Shipstone, 1985; Osborne et al, 1991; Borges & Gilbert, 1999) and floating and sinking (Inhelder & Piaget, 1958; Howe, et al., 1990; Havu-Nuutinen, 2005). Although such converging findings reflect reliability and validity for the current work, it is clear that these do not enable the current research to move forward on issues of conceptual change. It is also acknowledged that there are some issues with matching the ages of the participants in order to provide direct levels of comparison, an issue that had been previously highlighted by diSessa (2008). In order to limit this difficulty the researcher compared the results with three important previous studies for each topic in order to enable the maximum coverage to previous literature. In order to provide appropriate comparisons within the original data collected for this work the schools selected were typical of the local demographic populations (Cohen et al, 2011; Arthur et al, 2012).

In terms of the models of understanding for electricity and floating and sinking revealed in this work, it was clear that although the electricity outcomes were largely comparable with previous studies, this work revealed additional models for floating and sinking that were not present in the research literature. This, in part, may be explained by the tendency for previous floating and sinking research to focus on density (Inhelder & Piaget, 1958; Howe, et al., 1990) whilst this work introduced the

more 'global' forces concepts and these may be more difficult particularly for the younger children. It can also be proposed that the current work has only been able to provide a single snapshot in time and the changes in the children's ideas that were observed may be the results of an instantaneous response to the tasks rather than representing long term effects. That said, some of the differences between the results of this work and the results presented in the research literature may be a result of the children's experiences with the National Curriculum. Notably, it is possible that more of the children were able to talk about electricity using scientific terms than those in Shipstone (1985) and Osborne, et al. (1991) because these children have received specific tuition as a matter of policy.

This work did adopt a new dialogic approach which has become popular in mainstream teaching following guidance from Alexander (2004). This approach also included the use of tasks designed to challenge ideas and incorporated science stories (Millar & Osborne, 1998). Reflecting on these activities, the children appeared to enjoy this approach as it allowed them to explore their ideas without feeling that they were incorrect. The conceptual challenge tasks were well received by all. Finally, the science stories introduced did appear to be beneficial. In some cases the children showed humour when discussing Archimedes' discovery. The structure of the activities undertaken appeared to be helpful for eliciting the children's ideas and did provide a focused background for the science topics studied. It was interesting to note that although the responses to the electricity probes could be altered by the context (e.g. the number of bulbs in the circuit), this influence was consistent across all age groups of children. One final limitation of the current study regards the researcher's background. The researcher is a psychologist rather than a qualified teacher or science educator. Being a psychologist was, however, considered to be an advantage when undertaking the literature review and for appreciating aspects of concept development and change that may have been more challenging for an educator who may not have been trained in this area in detail.

### 8.2.5 A Multimodal Approach to Studying Children's Ideas

In this section, a summary of findings from the multimodal aspects of the research undertaken here is presented and discussed, in particular this section aims to respond to the research question regarding whether the multimodal analysis adds to an understanding of children's ideas in science. The findings highlight the frequency with which gestures occurred during the science activities, the ways that these appeared to change between the different age groups, and the ways that gestures were used to support the content of verbal and written speech or add to the understanding of what children know by providing additional knowledge that was not contained in the more well studied response types. The additional knowledge provided in the gestures revealed important aspects of children's ideas not otherwise noted in their verbal or written responses and drawings. Therefore it is proposed that studying gestures is important if we are to understand all aspects of children's ideas. A typology of children's gestures specific to the two topics studied in detail and, in some instances perhaps, to science as a whole is proposed.

### 8.2.6 Gesture

As introduced previously, multimodal research is a new and evolving field that is just beginning to emerge within science education (Crowder & Newman, 1993; Crowder, 1996; Goldin-Meadow, 2000, 2003; Roth & Lawless, 2002; Blown & Bryce, 2010; Padalkar & Ramadas, 2011). Studies have taken place across a number of different age groups including primary and secondary school children, although typically the studies explore interaction between the children and the adults involved, rather than child to child interaction as has been studied to some extent in this work. Previous multimodal research has been most prominent in the UK and North America.

According to Jewitt (2013), "*Multimodality is an inter-disciplinary approach drawn from social semiotics that understands communication and representation as more than language and attends systematically to the social interpretation of a range of forms of meaning making.*" Multimodality proposes that communication occurs across a range of different levels which includes the traditional constructivist approaches to studying children's ideas such as speech, writing and drawings but

also extends to gestures and other non-verbal behaviour (Kress, et al., 2001). According to the important and early work of Kress, et al., each of these different levels permits the transmission of knowledge according to different affordances (e.g. in non-verbal responses it is possible to represent information that may not be contained in speech because of the structure and rules of this communication medium). Therefore, and in order to gain a fuller understanding of children's ideas, this work attended to a wider range of response types which may permit a fuller more detailed understanding of what children know and can do. However, multimodal research is not beyond criticisms these include O'Halloran and Smith's critique (in press) that many multimodal studies typically analyse transcripts even though they explore different response type other than verbal language. Furthermore, O'Halloran and Smith bring to the fore issues of transcription as well as reproduction for later publication whilst Jewitt (2013) proposes that multimodal research can seem impressionistic in its analysis (Jewitt, 2013). Indeed, it is entirely legitimate to ask how a gesture or an image has the same meaning to the 'producer' as that interpreted by the researcher. Equally, it could also be argued that the same criticism is true of any verbal or written response or drawing (e.g. Johnson and Gott 1996). It has also been suggested that multimodal research is intensive in terms of both time and effort (Jewitt, 2013) and although this analytical approach can facilitate a fine grained capture of details through specific instances, it may be far more difficult to generalise such findings to a wider context. Finally, can it be questioned whether it can be concluded with any certainty that the gestures that children produce are indeed meaningful and not just coincidental movements that occur. On this last point, the long history and majority of gesture research has established that children's gestures are valid and reliable sources of information that may not be present in speech (Crowder & Newman, 1993). Importantly, and according to Goldin-Meadow & Singer (2003), by attending to gesture it may be possible to track and determine when some children have reached an optimum moment for receiving tuition. This literature supports the case for the inclusion of analyses of gestures alongside other response types if we are to understand all aspects of children's ideas in science.

In order to complete the multimodal analyses undertaken in this study it was necessary to develop specific analytical tools to support this. Full details of these



tools are discussed in Chapter 5. The storyboarding technique, in particular, was developed in order to effectively summarise the content of the science activities alongside the complexity of data anticipated (e.g. Figure 68). This approach to data analysis required extensive development in order to capture enough information so that it could be used to inform the conceptual change debate. Storyboarding has never been used in this context before and as such it could be vulnerable to researcher bias. One advantage of storyboarding, in addition to facilitating the handling of complex data sets, is that it does negate the requirement for extensive transcript extracts as it effectively summarises important components of any analysis undertaken.

As highlighted in Chapter 5, part of the analyses undertaken in the storyboards explored the findings of Goldin-Meadow's work (2000, 2003) which suggested that a mismatch between the content of children's verbal responses and children gestures revealed an 'optimum' opportunity for children to learn from tuition. This analysis explored what an understanding of gesture could add to the other response types in order to understand children's ideas fully. In addition, the importance of studying the content of gestures was further underpinned by Karmiloff-Smith's model of conceptual change (1992), discussed in more detail in Chapter 3. The analyses exploring whether incoherence between the content of gestures and other responses types such as language could be used to predict change produced variable results which also appeared to be mediated by the science topic studied. The results from electricity revealed that in the Year 2 group study (Figure 68) there was coherence between the content of the children's gestures and their verbal responses and no evidence of conceptual change at the end of the activity. In the Year 6 group study there was incoherence between the gesture and verbal response of one child, Rachel, and coherence for the other children. But there was clear evidence of a change in ideas between the beginning and end of the tasks. Finally, in the Year 9 group study, there was evidence of incoherence between the gestures and the verbal responses of one child, Janet, and coherence for all the other children, again, with clear evidence of conceptual change for all group members. Interestingly in the floating and sinking group studies, all three age groups demonstrated coherence between the content of their verbal responses and their gestures. Whilst there was no evidence of conceptual change for the Year 2 children, the other two age groups

did show clear development in their ideas between the beginning and the end of the activities. These results appear to show mixed support for Goldin-Meadow's proposal that a mismatch between the two response types may signify that additional tuition would be beneficial for the developing the child's ideas.

However, such a conclusion must be drawn with care. Goldin-Meadow's work investigated a different topic area, notably mathematics, and it may be that her results are more context specific than was first thought.

Overall, the storyboarding approach did have utility for sufficiently permitting the research to highlight important discussions between the children as they worked through their ideas. However, it is suggested that this approach to analysis was not able to capture the dynamics of conceptual change at 'fine grained' level required. In order to further assess the storyboarding approach it is proposed that further research should be undertaken in order to explore its utility in other contexts and for other science topics.

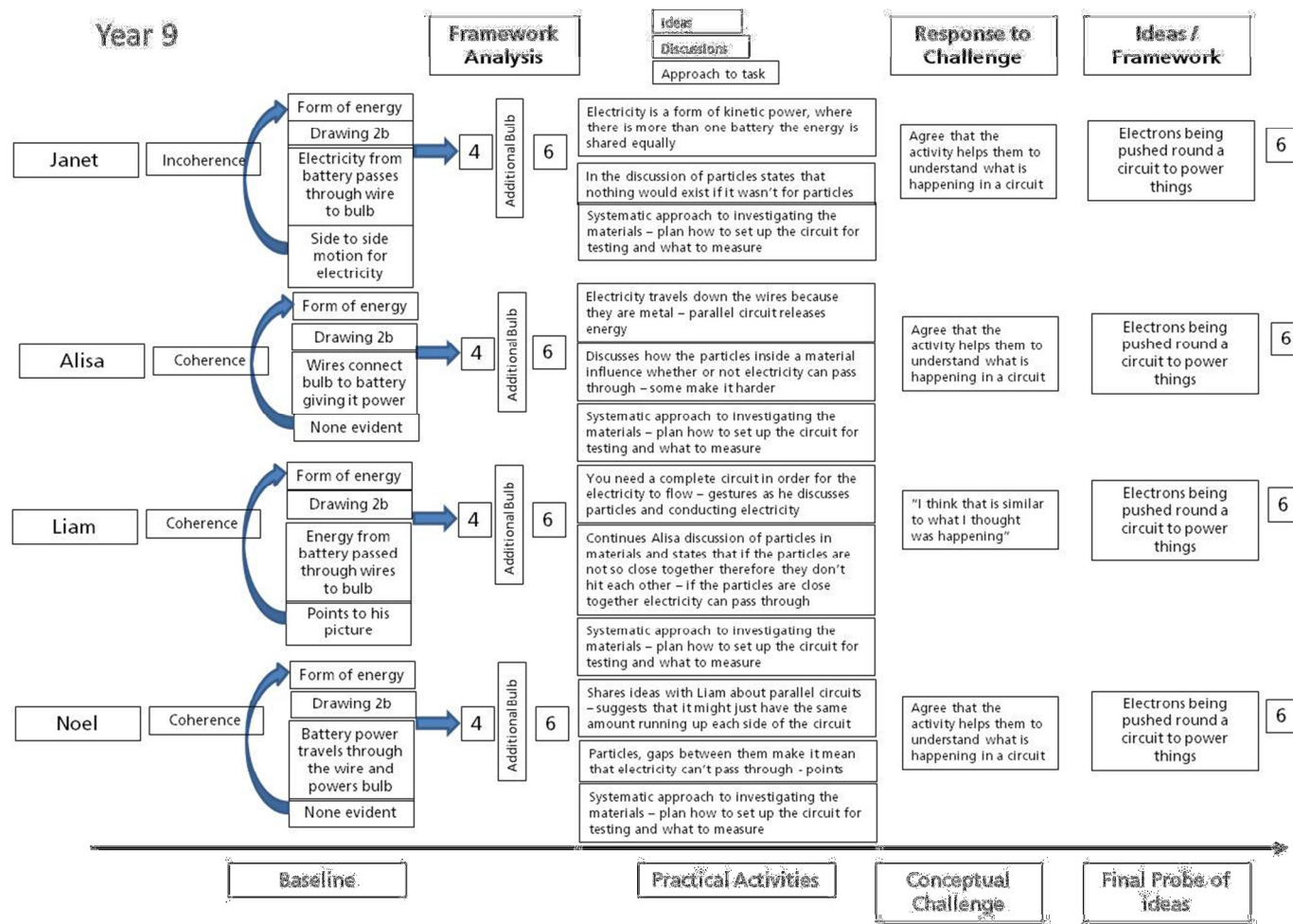







Figure 68: Storyboard from Year 9 electricity activities.

### **8.2.7 The Importance of Gesture: Towards a Typology**

One of the important aspects of the current work involved exploring the different types of gesture that the children used during discussion of their science ideas and if these gestures did appear to contain meaning not always evident through other forms of communication. Whilst there is previous work which has mapped the different types of gestures that are used across topics (e.g. McNeill, 1992; Roth, 2000), few have aimed to map those that are specific to science. In order to explore the different types of gestures that the children produced and in order to propose what these may reveal about children's ideas about electricity and floating and sinking, an initial typology of gesture was established from the pilot study data collected during Research Phase 1 and the main stage data collected during Research Phase 2 (Table 88). This typology was published for a professional audience where it met with interest and favourable review (Callinan and Sharp, 2011). Five distinct categories of gestures were identified and these five categories of gestures all appeared to serve different functions.

Contrary to previous research by Crowder and Newman (1993) and Crowder (1996), the gestures that the children used here were rarely, if ever, redundant. Whilst it is difficult to say with certainty why this may have occurred, in part this might be explained by looking at the context in which the research took place. Crowder and Newman's work took place in a general classroom setting where there may have been more opportunity to utilise redundant gestures. By contrast, this work aimed to provide the children involved with an opportunity to operate multimodally and also to probe and potentially change their ideas. This focus on eliciting responses to specific questions and tasks may have influenced the types of gestures used and therefore only gestures that served a specific communication function may have been observed.

Scientific Gestures		
Type of Gesture	Definition	Example Photograph
Referential	Pointing to objects, pictures or people in order to complete / extend discussions of ideas	
Representational	Acting out the behaviour of objects, people or events in order to show how something works or happened	
Expressive	Using the hands to represent values such as the strength of responses in objects, people or events in order to show how they think they work	
Thinking	Including finger drumming, head holding, face and hair stroking – used when considering how to respond to a question, problem or situation	
Interpersonal Gestures		
Type of Gesture	Definition	Example Photograph
Social	Eye contact, body movement, touching or nudging others – used to elicit a response from other members of a group	

*Table 88: The different types of gestures identified in both the pilot studies of Research Phase 1 and the results of Research Phase 2.*

By way of example, and as discussed earlier in Chapter 6, Mike in Year 2 used a referential gesture to add to his discussion of his circuit drawing (Table 28, Figure 30). By pointing to where he thought a bulb holder should appear, it was possible to have a clearer understanding of what he thought should be included and where. The storyboard from the Year 6 study (Figure 32) provided support for the notion that children's gestures can be used to appreciate knowledge that is not represented in speech at all. Rachel's responses showed that in her speech she describes electricity using its function (e.g. that it powers things), however, her representational gesture (a circular motion drawn with her hand) demonstrated that she also had an

awareness that electricity flowed through the circuit too. Similar findings were evident within the floating and sinking tasks. Daniel in Year 6 used a representational gesture to support his discussion of what he thought floating was (Table 75, Figure 57). In his verbal response, he proposed that he thought floating occurred when things stayed above the surface of the water and did not go below it. This verbal response provided a location for the floating object but his representational gesture extended this discussion by showing how he thought both a floating and a sinking object would behave (e.g. as he talks about objects going underwater he lowers his hands as though they were the object). Interestingly, the gestures of the Year 9 children produced during the floating and sinking tasks frequently featured the children anchoring their discussions to objects. For example, when Nigel, a Year 9 boy, discussed an object that had surprised him, he picked it up and rotated it between his fingers as he spoke (Table 87, Figure 66). This use of gesture and object handling was interpreted as providing support for the content of the children's speech.

As highlighted previously, expressive gestures were used by the children in order to show values such as the strength of responses, for example, how the light from a bulb would appear. In one example, a Year 2 child, Selena, used just such a gesture in order to show how she thought the light would behave once she had completed her circuit (Table 23; Figure 27). Thinking gestures were also prominent in the video corpus, one example of this form of gesture was drawn from the floating and sinking activities. Alice, a Year 6 child, was discussing how the shape of a boat helped it to float (Table 63; Figure 51). As she discussed these ideas she stated in her verbal response that she could not remember and as she made her verbal response she sat on her hands and rocked slightly from side to side. This movement did not appear to be a stress response instead it appeared to be used as a non-verbal cue that she was considering her thoughts and was unable to respond at that time. As the researcher moved the questioning on, Alice stopped the gesture and returned her hands to the table. The final form of gesture found in the video corpus highlighted the importance of social interaction between the children. These social gestures were common across all age groups. In one example the social gestures between two Year 9 children, Janet and Noel, showed how they supported each other during discussions (Table 25; Figure 28). In this example, Janet named

materials that she thought were electrical insulators. As she named the materials, Noel pointed to examples on the table, at the same time Janet nodded to acknowledge Noel's non-verbal contribution to the discussion. When comparing these results to the work of Crowder and Newman (1993; also Crowder, 1996), there was clear evidence of the children using gestures to both complete and extend their verbal and written responses and drawings. Thus, these results highlight the importance of studying gesture alongside other response types.

### 8.2.8 Gesture, Electricity and Floating and Sinking

Each of the five categories of gesture identified are proposed to have their own specific function and meaning and were found to be evident in discussion about electricity and floating and sinking and across all three age group, albeit to varying degrees. An overview of the occurrence of the different types of gesture is presented in Table 89.

<b>Gesture</b>	<b>Referential</b>		<b>Representational</b>		<b>Expressive</b>		<b>Thinking</b>		<b>Social</b>		<b>Total</b>	
<b>Topic</b>	<b>E</b>	<b>F&amp;S</b>	<b>E</b>	<b>F&amp;S</b>	<b>E</b>	<b>F&amp;S</b>	<b>E</b>	<b>F&amp;S</b>	<b>E</b>	<b>F&amp;S</b>	<b>E</b>	<b>F&amp;S</b>
<b>Year 2</b>	38	9	33	28	6	6	8	0	15	22	102	65
<b>Year 6</b>	21	8	48	79	18	13	4	6	31	29	122	135
<b>Year 9</b>	23	9	15	12	4	4	5	8	15	20	62	53
<b>Total</b>	82	26	96	119	26	23	17	14	61	71	286	253

*Table 89: The frequency of the different gestures used by the Year 2, Year 6 and Year 9 children across both electricity (E) and floating and sinking (F&S).*

As shown in Table 94, with the exception of the social gestures, the results suggested that of the four categories of science gestures, the referential and the representational gestures were more common than the expressive and the thinking gestures. The referential gestures were consistently more common during the electricity tasks than they were during floating and sinking. These forms of gesture provided additional information that was not readily available in the children's verbal reports. It is proposed that this may have occurred because of the simpler and more concrete nature of the floating and sinking tasks relative to the more abstract and conceptual content of electricity. The representational gestures were more common

overall during the floating and sinking activities. These forms of gestures were typically used during discussions in order to show how the children thought the objects behaved in the water. Thus it is proposed that the type of gestures used may be influenced by the context and topic explored. Overall, thinking gestures occurred less frequently than the other types. One possible interpretation of this data is that often children were given probes to which they could respond and when children appeared to be struggling the researcher moved the activity on in order to minimise the children's discomfort. Interestingly, when comparing the frequency of gestures produced by each age group, the Year 9 children appeared to use the least amount of gestures in total and the Year 6 children appeared to use the most. These results support the notion that there may be some age related changes in the use of gesture.

The analysis also revealed that some gestures were unique to each science topic. During the electricity tasks, for example, the children across all three age groups used representational gestures in order to draw out paths showing how they thought the electricity moved in a circuit (Figure 69). As shown in Figure 69, the children either used their fingers to trace a path above the circuits, their whole hands or in some cases both hands to draw paths. This form of representational gesture never occurred during the floating and sinking activities. It was particularly useful in this context for revealing the underlying models about electricity that the children held.





*Figure 69: Typical representational gestures that occurred across the three age groups of children during their discussion about circuits. The gestures represented the ways that the children thought the electricity moved through the circuit.*

As with electricity, there were some gestures that typically occurred across all three age groups of children during the floating and sinking tasks. These gestures were also representational and revealed information about how floating and sinking objects behaved. As is shown in Figure 70, the representational gestures for floating typically featured the children holding their hands steady in the air. Often the gestures featured hands held flat with the palms facing downwards or the hands held adjacent to each other in a 'c' and a reverse 'c' shape. In all cases, these gestures represented the object remaining stationary suggesting that the children thought that floating objects remained still in the water. Interestingly, across all three age groups, similar gestures were also produced when the children discussed their ideas about sinking. The representational gestures used when discussing what the children thought sinking was always involved some form of downwards motion. Some children held one hand flat, representing either the water or the bottom of the tank, whilst the other hand was lowered towards it. Some children used just one hand to make a downward motion towards the top of the table that they were seated behind

and some children used their fingers to point downward. These gestures indicated that the children perceived sinking as involving movement towards the bottom of the water.



*Figure 70: The top row of photographs shows typical representational gestures used during the children's discussions of floating, the bottom row shows typical representational gestures when discussing sinking.*

One interesting overall finding was that there appeared to be no gestures that were considered to be particularly atypical in the fully transcribed group studies or at the beginning and the end of all of the activities. Whilst this may seem unusual, this result may, in part, be explained by the highly structured nature of the activities. The children involved were on task throughout the activities and this may have prevented unusual outcomes. In terms of validity and reliability the consistency between the types of gestures used during the activities does appear to support the notion that the categories of gestures identified are meaningful. That is, they occurred regularly, repeatedly and independently across groups. The five categories of gesture did occur both in the pilot studies and in the main data collection of Research Phase 2. This again supports the notion that the methods used to capture the gestures were valid and reliable. Furthermore, the consistent re-occurrence of similar gestures

supports the notion that these are worthy and important aspects requiring further study.

### **8.2.9 Limitations of the Multimodal Approach**

The multimodal, task-based approach to studying children's ideas is considered a particularly original contribution of this work to the literature exploring conceptual change in science. As such, there are a number of important limitations that must be acknowledged. Firstly, the use of gesture in science education research is not without criticism. Krauss (2001) proposed that the communicative function of gesture is still unclear and a matter of controversy. Although it is clear that gestures exist, at this time whether gestures are linked to language or memory retrieval is still debated. Roth and Lawless (2002) proposed that although it appears that gesture scaffolds language development, the mechanisms that underpin gesture are less well understood. However, despite these issues the data presented here does support the notion that gestures are prominent in the children's responses and these do appear to have a communicative role.

The storyboarding approach developed for this work can also be critiqued. Storyboarding was a particularly novel aspect of the work in this thesis and was created specifically as a means for comparing the different response types that the children used when discussing their ideas during the activities. As this was the first application of this approach to analysing multimodal data, it is difficult to say with certainty whether or not the method will prove to be reliable in the context of other studies. However, in this project it was clear that storyboarding did provide the opportunity to directly compare the contents of the different responses in order to highlight any incongruence between them (e.g. whether there was a mismatch between the contents of the gestures and the contents of the verbal responses). In addition, storyboarding did facilitate the effective summary of a large amount of data in one place thus making it possible to gain an overview of the group studies that had been fully transcribed and making it possible to effectively track any changes between the baseline and end assessments of children's ideas.

As with the traditional constructivist approach the multimodal analysis must also address the criticism presented by Johnson and Gott (1996). This criticism is important particularly when considering the interpretation of the children's gestures that was made by the researcher. It is important to consider that although it would have been desirable to have returned to the children in order to elicit their interpretation of the gestures used, that approach was not possible in this study and therefore the researcher was solely responsible for interpreting the gesture. Although Johnson and Gott highlight that it is difficult for an adult to interpret a child's frame of reference, great care was taken during analysis in order to triangulate the findings and the researcher was able to use knowledge of both the children and the context of the research in order to support this. It was because of this that the researcher had ensured that all activities were delivered as a participant rather than by a class teacher. Whilst the researcher was not a fully trained teacher, there was consistency in the delivery of the activities and tasks across the groups studied. The researcher had also observed, studied and piloted the activities and tasks in consultation with the class teachers themselves and with reference to the research literature (Inhelder & Piaget, 1958; Shipstone, 1985; Howe, et al., 1990; Osborne, et al., 1991; Borges & Gilbert, 1999; Havu-Nuutinen, 2005).

#### **8.2.10 Why Study Gestures?**

The results to the work undertaken here support the notion that a multimodal analysis of children's ideas adds positively to the existing body of literature which aims to provide an understanding of children's ideas for different science concepts. Gestures can contain additional conceptual information that is not contained in any other response type such as verbal or written responses and drawings and this can help researchers and indeed teachers to appreciate, interpret and understand the ideas that children have. The analyses undertaken in this project also highlight that the social gestures that children use can be particularly revealing about the impact that peers can have on children's knowledge growth, the way that concepts are negotiated when undertaking collaborative work and the information that children are comfortable with revealing when their ideas are probed in a group context. It is suggested that future research should aim to incorporate such detailed analyses of gesture in order to provide a holistic overview of children's ideas. It is argued that

gestures illuminate meaning and reduce ambiguity associated with other response types such as language. Gestures are a useful form of non-verbal communication particularly when language is under-developed.

### **8.3 Research Question 2: Can such analyses be utilised in order to explore and contribute to an understanding of the dynamics of conceptual change?**

In this section what multimodality and an analysis of gesture considered alongside more traditional approaches to eliciting children's ideas contribute to more theoretical perspectives surrounding conceptual change is discussed. In the first instance, the discussion returns to the earlier constructivist theorists introduced in Chapters 2 and 3 and considers these within the context of this research. Four selected models of cognitive conceptual change are revisited in light of findings and it is highlighted how these models have been used in order to support and guide the analyses undertaken as part of this work. The notion of 'hybridity' is introduced and developed as a means of reconciling the results to the work.

#### **8.3.1 The 'Early Years'**

As outlined earlier in this thesis, the early European constructivists such as Piaget (1929) and Vygotsky (1978) played a vital role in establishing constructivism as a way of understanding how and what children learn. These important theorists proposed for the first time the active nature of knowledge construction and the ways that this could be influenced by internal mechanisms and social environment. This language of constructivism has been far reaching and has shaped the ideas of contemporary constructivism as it is understood within science education today (Driver et al, 1994). Furthermore, the work of these two important theorists also underpinned the later work of the North American constructivists and Ausubel in particular (1968, 1978). Ausubel's work provides an appropriate foundation for the findings drawn from this work. Ausubel proposed that language as a lone medium may not be enough to assess and measure children's knowledge, especially if researchers and teachers were to understand fully the ideas that children have:

*“Prior to being verbalised, new concept meanings also typically exist for a short while on a subverbal level – even in sophisticated older learners.”* (1978, p.105)

Such a notion resonates with the work in this thesis which adopts the principles of multimodality and present evidence that knowledge can be held and indeed demonstrated in a range of different ways including through gesture. The results of the work undertaken here do reflect some of the overarching principles of global constructivist, for example, in agreement with Piaget (Inhelder & Piaget, 1956) the younger children were not able to further develop their ideas from the conceptual challenge tasks. These findings could be interpreted as a result of the children not being at an appropriate developmental level in order to learn the more complex concepts. There was also some evidence of both assimilation and accommodation in the data presented (Piaget, 1929). In terms of Vygotsky’s theories (1978), there was evidence of social interaction supporting learning in the groups and indeed such social construction of knowledge underpins the dialogic teaching approach adopted in this work (Wells, 2011; Alexander, 2004). Finally, there was evidence of Ausubel’s ideas in the results to this work. The children did show evidence of ideas that were not represented in their speech and this evidence did highlight the potential for the children’s ideas to be misrepresented in the final analyses if the gestures were not accounted for. However, the results were so far reaching that no discrimination was possible suggesting that although these global theories are useful they are not specific enough to permit the detailed analysis required by this work.

Despite early criticism regarding the difficulties of accessing children’s ideas, early constructivist views gave way to a more domain-specific view of learning (e.g. science as a subject) introduced by Driver and Easley (1978) and later championed by Driver (1995). Driver’s view that children already entered the science classroom with pre-existing ideas about the science topics that they were studying promoted the notion that learning was perhaps best conceived of in terms of conceptual change. The notion of change led to the emergence of the alternative frameworks movement and subsequently to the publication of a number of different theoretical models to account for findings. Alongside this development was acknowledgement of the ontological assumption that children have their own ideas about the world in which they live and the epistemological assumption that it is possible to explore,

measure and record these, to classify them, and to track the changes in them as they develop. Of all the contemporary models of conceptual change available today (see Figure 9; Table 3), four were selected as having achieved prominence and worthy of further exploration: Vosniadou and Brewer (1987), diSessa (1988), Karmiloff Smith (1992) and Luffiego, et al. (1994).

### **8.3.2 Conceptual Change: A Comparison of the Traditional and the Multimodal Approach**

In order to undertake the traditional analysis three of the four models of conceptual change that were selected in Chapter 3 were applied (diSessa, 1988; Vosniadou and Brewer, 1987; and Luffiego, et al., 1994). Vosniadou's approach to conceptual change highlighted the importance of using children's responses in order to tap into the underlying mental models that were being applied in response to science tasks. As previously discussed, according to Vosniadou conceptual change takes place when the mental models that a child uses is altered, this can be at a weak or a radical level (Vosnidaou & Brewer, 1987, see Chapter 3 for further details). This particular model guided the analytical approach applied during the framework analyses undertaken in Chapters 6 and 7. Fundamentally, according to this model of conceptual change it should be possible to highlight knowledge development if the frameworks of understanding that the children use differ and develop throughout the course of the practical activities and by exploring differences in frameworks between the three age groups it should be possible to infer how knowledge develops over time. Vosnidaou's framework can be considered to assess concepts at a 'coarse' grained level, largely because this approach refers to 'theory' style structures. In contrast diSessa's (1988) important work highlights that knowledge change and growth can take place at a 'finer' grained level. When applying diSessa's work to the issue of conceptual change the importance of studying the links between more detailed pieces of information is highlighted, therefore, this approach also influenced the analytical framework applied and a theme analysis of the children's ideas for the two concept areas studied was undertaken. The theme analysis permitted the researcher to interrogate concepts at the finer grained level required and explore the links that children were making in detail both at the beginning and the end of the tasks. Finally, Luffiego's work (1994) was used as an overarching framework in order

to provide a non-linear explanation for why some children changed their ideas in the ways that they did, why some children did not and why some children showed evidence of knowledge regression as evidenced in Chapter 6 and 7.

As discussed previously, in order to explore Vosnidaou's model of conceptual change it was important to assess the children's ideas in terms of the frameworks of understanding that they showed for the different concept areas (electricity and floating and sinking). The work discussed here used the frameworks that had already been established in the literature (Osborne et al, 1991, for electricity and Havu-Nuutinen, 2005, for floating and sinking), however, in the case of the floating and sinking activities the existing frameworks drawn from the literature required additional development in order to accommodate the range of ideas generated by the children participating in this project. The results drawn from the electricity activities appeared to show some support for Vosniadou's proposal that conceptual growth can be perceived as a change in the frameworks or mental models of understanding that children demonstrate for science concepts. Referring back to Table 19, the framework analysis revealed that across all three age groups some children demonstrated evidence of radical restructuring of ideas following tuition, with some children appearing to change the framework that they were applying between the beginning and the end of the activities. The framework approach to analysis was useful as it helped to show how ideas had progressed both within and between the three groups of children during the research project. Importantly, this analytical approach demonstrated evidence that the older children's ideas became more scientific over time (e.g. between Year 2, Year 6 and Year 9) and in some cases became more scientific over the course of the research activities.

Similar results were evident in the floating and sinking data (Table 57), which demonstrated that with the exception of the Year 2 children, some children did appear to change the frameworks of ideas that they were applying at the beginning and the end of the activities. Interestingly, in this work, there was no evidence of a change in the frameworks used by the Year 2 children after the conceptual challenge task even though this was applied in a collaborative group context. These results contrast with previous findings that had suggested that provided groups were structured to permit discussion children's ideas could be changed (Howe, et al.,



1991; Havu-Nuutinen, 2005). However, it is important to note that the children in Howe, et al.'s study were older than the Year 2 sample in the current work and Havu-Nuutinen's work focused on just 10 younger children but sought to teach density rather than an appreciation of forces. Thus the results may be specific to that sample or to density concepts. It could also be proposed that the 'global' forces concepts introduced in the current work were too advanced for the Year 2 children in this study and although at the time of tasks the children may have been able to apply the concepts they may have found it difficult to reconcile these with the frameworks that they already held. Perhaps it is possible that these were concepts that the children may have been reluctant to believe (Driver & Bell, 1986), or as Luffiego, et al. (1994) highlighted this study may have captured the unanticipated outcomes that can occur when children are learning new information in the science classroom. Overall, the application of the Vosniadou's approach to conceptual change was helpful for tracking changes in the overall 'theories' that children had for the two science concepts, however, because the changes were measured using frameworks it was difficult to tell how these ideas had moved forward and which were the important concepts that had facilitated this change. In order to begin to explore the changes in more detail the 'finer grained' model proposed by diSessa (1988) was also applied in this study.

It was proposed that exploring the themes that children discussed at the beginning and the end of the tasks was helpful for revealing some support for diSessa's model of conceptual change (1988). According to diSessa's model it is important to map the different links that are made between individual pieces of information or p-prims (see Chapter 3 for full details and Chapters 6 and 7 for a fuller discussion of the results to this work). The results drawn from the electricity data (Table 18) demonstrated that some children showed evidence of making new links between different concepts. For example, following conceptual challenge, some Year 6 children began to make links between the p-prims power and energy. These results suggested support for the proposal that this work had been successful for capturing conceptual change at this level. Interestingly the results for floating and sinking activities revealed no change in the links made between individual ideas as assessed by theme analyses in the youngest children's (Year 2) definitions of what they thought was meant by the terms floating and sinking (Tables 55 and 56). These findings may be due to the children's

ages or because the conceptual change task introduced concepts that were entirely novel to these children, therefore they found it difficult to add these into their existing ideas. There was evidence of conceptual change at p-prim level (diSessa, 1988) in both the Year 6 and the Year 9 children. Interestingly these results showed that the Year 6 children were able to discuss the new ideas introduced in terms of the themes included in their ideas of what electricity is. Similar findings were evident in the Year 9 children. These results as a whole supported the use of the conceptual challenge task and the application of diSessa's model of conceptual change. In addition, the overarching framework provided by Luffiego, et al.'s model (1994) helped to provide support for why some children changed their ideas and some did not. According to Luffiego's model the children's existing ideas and experiences heavily influence what, if any, learning can occur and this can make the outcomes unpredictable. However, there was evidence of new links being made between p-prims for both the Year 6 and Year 9 children. For example, some Year 6 children began to use the terms 'upthrust' and 'gravity' in their discussions and these had not been present during the baseline testing. These results may highlight the links being made between already existing p-prims and the new ideas about forces that were introduced during the sessions. One problem with this approach to analysis was that although it was possible to highlight that some children had changed their ideas and to show how the new ideas had been linked together, it was not clear how these ideas had changed during the course of the activities. It could have been that the children had made many revisions to the links between concepts as they worked through the different tasks but that these were not captured by merely measuring ideas at the beginning and the end of the activities. Therefore this made responding to the models of conceptual change particularly difficult, it was clear that there was some evidence of change but this evidence could still be interpreted into all three models of conceptual change discussed so far, albeit at different levels depending on the 'grain size' studied.

As discussed earlier in this chapter and in previous chapters, the work presented here also utilised a new and innovative multimodal, task-based approach to studying the development of children's ideas in order to explore what if anything, this form of analysis could add to the conceptual change literature. In order to undertake this analysis timeline diagrams were developed using the work of Givry and Tiberghien

(2012). In the earlier methodology chapters (4 and 5), it was proposed that by utilising such an approach it may be possible to capture and map the dynamic processes of conceptual change as they unfolded in 'real time'. This was achieved as evidenced in the development of timeline diagrams, one of which containing further annotations is shown in Figure 71. This particular approach to analysis drew heavily on the work of Karmiloff-Smith (1992) who had highlighted that a significant part of children's knowledge growth was moving concepts through different levels or representation until they became accessible to verbal responses. Karmiloff-Smith's model of conceptual change, discussed in more detail in Chapter 3, proposed that some ideas are accessible only through non-verbal representations particularly when these are in the early stages of formation. It was proposed that by analysing the data using an approach that focused on the gestures as well as the language that children used it may be possible to unpick aspects of the four models of conceptual change in order to assess their effectiveness for explaining the data generated in this study. As highlighted earlier in Chapter 3, there are number of issues with comparing the literature on conceptual change to date. These include the use of different age groups, different science topics and different methodologies, different conceptualisations of conceptual change, and language (diSessa et al, 2004; diSessa, 2006). In order to overcome this difficulty, this work aimed to evaluate the models of change using a bottom-up process.

### 8.3.3 Gesture and Conceptual Change

Whilst storyboarding was used to capture and compare different response types within the different science activities adopted, storyboarding alone could not provide sufficient information about conceptual change dynamics. In order to provide this level of detail it was necessary to develop a timeline diagram that might capture the different concepts that children used as they evolved over time. The timeline diagrams presented build on the work of Givry and Tiberghien (2012). In this important work, Givry and Tiberghien indicate how the complexity of the networks of concepts that children use when in science lessons can be illustrated. As with storyboarding, this approach did appear to have great utility for enabling the researcher to pinpoint how and when changes in the ideas presented did occur.

As indicated earlier, timeline analyses proved essential to studying conceptual change. Part of this change involved a detailed analysis of gesture and its contribution. The timeline analysis presented in Figure 71 highlights the significance of this analytical approach and the nature of the gestures captured. Figure 71 shows the timeline and its related concepts, some photographs of the gestures produced by the children when each of these new concepts was introduced, and notes proposing how the children's ideas have evolved. The photographs and concept maps are matched and numbered.

Following the timeline diagram it can be seen that the children initially used a single concept in order to explain what they thought floating and sinking was (1). This concept was associated with a related representational gesture that provided additional information not contained in their speech. Notably, Daniel's gesture highlighted how the object explored behaved in the water. This single concept idea was extended to included additional information (2) and again was accompanied by a representational gesture which this time shows how Daniel thought a sinking object would behave. In terms of change this could illustrate evidence of a weak form of conceptual change as the core concept (e.g. the location of the object in the water) remains central to the discussion. The evolution of the children's ideas continued to adopt what could be perceived as a weak form of conceptual change supported by gestures that extend the meaning contained in speech (3, 4, and 5). The evolution of

ideas mapped in this diagram went on to reveal increasing levels of complexity in the children's responses. Interestingly, however, during the further testing of objects the children introduced a new set of concepts. The children began to associate the floating and sinking activity with a method for testing the weight of the object (6). This point marked a departure from the concept previously used and may provide evidence of knowledge fragmentation. The children then returned to a discussion of object properties but this time with new ideas not previously represented (7). New concepts were introduced again (8, 9). The timeline then appears to mark a point of more radical restructuring (10, 11). Here, the children ceased discussing just the object properties in their ideas of floating and sinking and began to discuss how '*water holds the object up*'. This discussion revealed a new concept introduced during the conceptual challenge task but not discussed by the children before. Interestingly, there is also evidence of a change in the representational gesture that Daniel used when discussing floating. By comparing gestures (1-10), it is possible to see that he had changed the orientation of his hand from palm facing downward to palm facing upwards. This subtle but important change in gesture may be a non-verbal cue to the changes that have occurred in his ideas. Finally, the children now only discussed floating and sinking by applying a forces framework (11). It is suggested that by using timeline diagrams like this it is possible to map out how and when children begin to use new ideas in their discussions and this can reveal when there are changes both at a fine grained level (e.g. in the gestures that the children use) and at a more coarse grained level (e.g. in the frameworks of explanation that the children use for the phenomena being discussed).

It is proposed that the analysis of gesture is fundamental for uncovering the sometimes finer grained distinction between the models that children use when discussing their ideas (Taber, 2008). In the conclusion to Chapter 6 it was highlighted that in some cases it was only through attending to the gestures that it is possible to pinpoint the underlying models of understanding applied. Furthermore, the analysis of gesture facilitates the identification that some children may use more than one model of understanding depending on the context of the questions or the tasks in hand. In the example presented in Chapter 6, it was clear that Daniel used one model of understanding when discussing his ideas about electricity when using a simple circuit containing one battery and one bulb, and another model when

discussing a circuit contain one battery and two bulbs (Table 48, Figure 42). This particular finding not only supports the findings from previous literature (Shipstone, 1985; Osborne, et al., 1991), it highlights the importance of studying gesture alongside their other response types even when verbal responses may remain consistent.

While timeline diagrams were fundamental for enabling the effective mapping of how the children's ideas evolved during the activities one important criticism of this method was presented by Givry and Tiberghien (2012) who highlighted that the results contained in such diagrams cannot be extrapolated to other children. Thus the diagrams contained in this thesis can only map the ideas of the children studied in those groups and not other children outside of this work. However, despite this limitation, Givry and Tiberghien (2012) also state that one advantage of this approach is that it can be used to generate ideas that can be subjected to further testing with other groups of children. In the context of this work, this means that the results in the timeline diagrams can be tested for their validity and reliability in future samples in order to explore whether the patterns of conceptual change uncovered are typical.

The timeline diagrams appear to illustrate that all of the four models of conceptual change employed by this work in order to guide the different levels of analysis undertaken appear to have some utility when exploring children's ideas. It could be suggested that perhaps one approach to understanding these results and the application of each of these models at different levels is to explore the notion of hybridity, whereby a single model of conceptual change that utilises important ideas from the four discussed in this work is applied in one coherent framework.

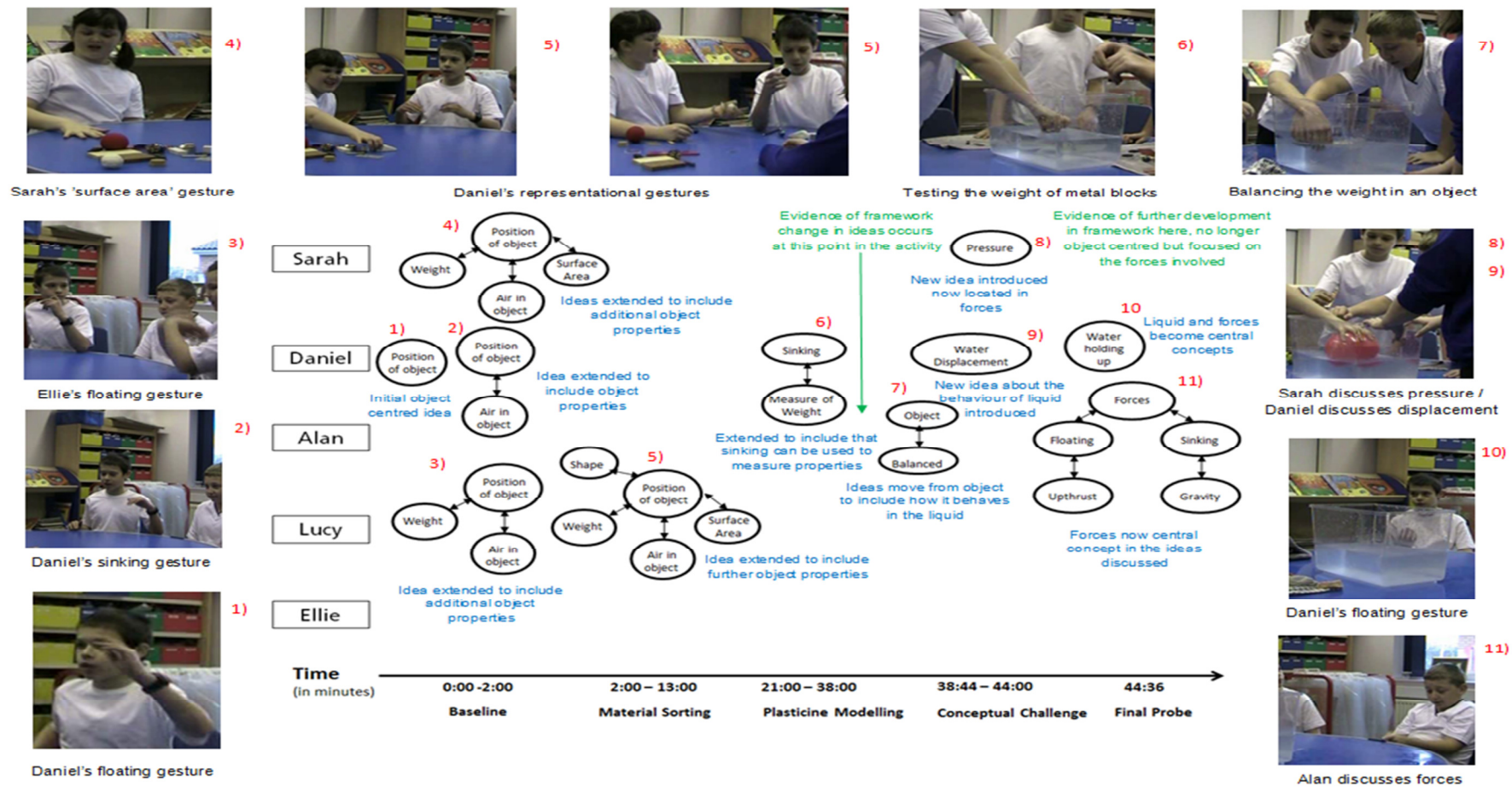


Figure 71: A timeline analysis of the Year 6 floating and sinking group study, further annotated to show how and when changes in ideas occur.

### **8.3.4 A Development of Ideas: Hybridity**

Perhaps one feasible explanation which could account for the findings presented here, namely the application of four existing models of conceptual change, is the notion of 'hybridity' and a 'hybrid model of conceptual change'. A hybrid model of conceptual change seems appropriate particularly if the initial mapping of ideas takes the basis of diSessa's p-prims (1988). These new concepts are mapped in isolation to specific stimuli. Such stimuli may not always be available for verbal report and may therefore only be identifiable when analysing gesture alongside the verbal reports given. Thus Karmiloff-Smith's (1992) views are essential. Once further experience is gained, these p-prims begin to evolve using both weak and radical processes (Vosniadou & Brewer, 1987) once 'theory-like' structures begin to form. Sometimes, for example, new information is merely added to the p-prim giving rise to weak changes. At other times, however, the new information forms the core of the concept and the existing p-prim becomes attached as a minor component giving rise to more radical changes. As shown in the findings from this work, it was not always possible to predict when the children would change their ideas even when the gestures of the children were compared to their verbal responses (Goldin-Meadow, et al., 2003). This finding can be explained by Luffiego, et al.'s model of conceptual change involving chaotic systems (1994). Luffiego's work proposed that the brain like any other non-linear and dynamic system is sensitive to certain initial states (e.g. previous experiences and learning) and as such the outcomes of tuition are unpredictable. This work is fundamentally important because it highlights why learning is often slow, incomplete and sometime inaccurate. These findings were evident in this work. Similar findings which have supported the notion of the application of chaos theory to the science classroom have been presented by Bloom (2001) and Sharp and Kuerbis (2006). There is also growing evidence from the neurosciences to underpin these constructivist learning ideas (Anderson, 1992, 1997, 2009).

Although such a hybrid model may at first glance appear purely speculative, other studies have alluded to the same (e.g. Taber, 2008). Fundamentally, Taber proposed that the differences between the two competing models proposed by Vosnidaou and diSessa may be related to 'grain size', and that both models may be,



as here, combined in order to explain how conceptual change occurs in more detail. According to Taber in the first instance, pieces of information need to be created. These then become organised into theory-like structures and are subsequently subject to weak and radical conceptual change. The overall results from the current work did reveal interesting patterns of development in terms of the typical changes that were observed between the different age groups that may be subsumed under just such a hypothesis. For example, if and as this work does, change is being measured through a timeline analysis, each additional concept can be considered a 'small-grain sized' piece of information and it could be suggested that changes occur through the links being made between diSessa's p-prims. However, if the comparison is at the level where entire frameworks of ideas are being measured (as with the beginning and end of activity comparisons provided in Chapters 6 and 7), these represent 'larger grains' and Vosniadou's views of weak and radical restructuring can be applied in order to explain the findings.

In order to unpack this proposal, further evidence is drawn from this work. Outcomes revealed that ideas about electricity progressively moved towards more scientific concepts as the children got older. The youngest children often focused their discussions on the effects of electricity rather than the characteristics of electricity itself, whilst the older children discussed electricity as current that powered objects. It was noted that during the practical activities all three age groups of children appeared to understand the principles demonstrated in the conceptual challenge aspect of the task (namely, the metaphorical use of smarties to represent the movement of electrons in a circuit). However, when probed at the end of the activity only the older children (Year 6 and Year 9) actually showed evidence of changing their ideas, weakly and radically. For example, some Year 6 children demonstrated weak forms of restructuring by including the term 'energy' in their discussions. As well as evidence of weak restructuring, there was also some evidence of radical restructuring with some children completely changing the focus of their ideas to centre on the notion of electricity as a flow of electrons. A clear example of such radical changes in conceptual structure can be seen in the timeline analysis presented in Chapter 6. What was perhaps more interesting was that although there was evidence that the changes could be applied within Vosniadou's ideas of

conceptual change, the more minor changes evident could easily have been explained by diSessa's notions of conceptual growth.

Similarly, outcomes evident from the floating and sinking data revealed that the more scientific ideas were presented by the older children. In the initial elicitation phase a dichotomous relationship between floating and sinking was presented by the youngest children. As with electricity, although all three age groups of children appeared to appreciate the new scientific principles presented during the conceptual challenge aspect of the task (namely, pushing an inflated balloon into the water) and were able to contribute to discussions at the time, only the older children appeared to show evidence of change in their ideas elicited during the final probes. Examples of changes in ideas once again appeared to reveal evidence that could be explained by Vosniadou's framework of weak and radical restructuring. However, examples could also be explained through the application of diSessa's framework of how ideas develop and change. However, in this study there is also evidence that some of the children's knowledge does appear to be contained in gesture but is not articulated in other ways. This finding is congruent with Karmiloff-Smith's model of conceptual change which proposes that children's ideas can be portrayed within different modes of representation. Notably, some knowledge is held in action and must be re-represented before it is available for verbal report. Such findings may not have been previously highlighted in the research literature as they required a multimodal approach in order to capture the gesture data. Figure 71 shows how children frequently included additional information in their gestures that was not represented in any other response type. Figure 71 can also be used to highlight points of weak restructuring (1, 2, 3, 4 and 5), the possible development or use of new p-prims (6, 7, 8 and 9) and evidence of radical restructuring (comparison of the contents of 5 and 10).

The findings from this work highlight that a multimodal approach can be effectively used to map the dynamics of conceptual change and contribute to these debates. However, as with previous conceptual change research, one overarching caveat remains; although the changes can be mapped research such as this cannot specifically highlight the underlying mechanisms that support such changes. In order to address this limitation it is proposed that this research should be considered

alongside the neurological evidence presented by Anderson (1987, 1992, 2009) which has proposed a number of mechanisms in the brain that demonstrate support for constructivist ideas. It is also important to highlight that in this study only four of the most prominent models of conceptual change were investigated, as highlighted in Chapter 3, many more models exist and these other models may also have some utility. However, despite the vulnerability that this limitation places on this work, it is proposed that the results are largely congruent with previous conceptual change analyses and the notion of hybridity introduced by Taber (2008). Finally, one last critique can be drawn from pivotal work of Linder (1993). Linder presented an important challenge to the notion of conceptual change and proposed that perhaps it was better to conceive of such changes in ideas as a form of 'conceptual appreciation'. Linder also highlighted the importance of context and proposed that *"appropriateness of conceptualisation requires a context"* (p.296). Furthermore, Linder stated that the approach whereby the aim is to change children's ideas may be flawed and that it is perhaps better to teach children which context are appropriate for different ideas.

#### **8.4 Research Question 3: Do outcomes from the work in this thesis have any classroom application?**

As with any research project undertaken in a professional setting, it is important to consider the potential implications that outcomes may have for practice. One aim of this research was to produce work which might be helpful in the classroom. Although it can be suggested that the emergence and novelty of multimodality means that it has yet to be applied and tested in different contexts, initial findings appear to support a real need to begin to explore multimodality in real world settings. For example, Ausubel (1978) warned against a now common over-reliance on words alone when assessing children in the classroom. Indeed, Ausubel proposed that:

*"Since there is often a time lag between the correction of misconceptions and the revision of language usage, it cannot be assumed that conceptual confusion necessarily exists in all instances where words are used inappropriately."* (Ausubel, et al., 1978, p.104)

Even though Ausubel was discussing the lag between language and the development of ideas some time ago, there remains considerable scope for the application of his work in today's schools. It is suggested that an emphasis on language that is evident in teaching and learning, assessment and the curriculum today may overlook the importance of exploring other means of communication. Whilst it is commonplace in the early primary years for children's drawings to be used as evidence of learning this application in assessment tails off in older children's educational experiences (for example see assessment guidance for primary Harlen, 2012; and for secondary TLRP, 2009). The research presented here supports a view that there may need to be more scope within teaching and learning and particularly assessment for children to operate more multimodally. Assessment processes in particular can be heavily reliant on written responses and it could be argued that open video recorded discussions such as those used in this research may provide an alternative and more effective approach to assessing children's knowledge and the effectiveness of tuition. The approaches that children take when undertaking tasks of various sorts can be revealing and the interaction between children during tasks can also be informative when considering their understanding of complex science concepts. Teachers may also welcome such alternative methods of assessment as these may prove fruitful in relieving the stress that can be associated with written tests. On the other hand, the highly technical, multimodal, task-based approach here may prove time consuming and require training.

The dialogic teaching adopted in this work appeared effective in helping the children to discuss their ideas. Dialogic teaching has been strongly supported in the more recent teaching and learning literature and has been supported in science education (Alexander, 2004; Fisher, 2007; Lyle, 2008; Mercer et al, 2009; Heneda & Wells, 2010). It is considered advantageous over other forms (e.g. didactic) because of its ability to not only probe children's ideas effectively using different questioning strategies but has been shown to support children's learning because of its discursive nature in which children are able to work out their own ideas through talk in the classroom context.

Furthermore, and in line with previous constructivist models of teaching (e.g. Driver 1989), this work has shown evidence that when working with older children

introducing a conceptual challenge task can progress children's and help them to learn new concepts (e.g. Ogborn et al, 1996). Despite criticisms of constructivist models of teaching (Airasian & Walsh, 1997; Millar, 1989; Matthews, 2003; Taber, 2006) the work in this thesis, however, does offer some support for the adoption of a constructivist-based approach that directly challenges children's ideas, particularly for the older children.

Finally, considering learning in the classroom it could be argued that greater attention needs to be directed towards children undertaking practical activities as these do offer a unique opportunity to understand what they know and can do. The success of challenging ideas through practical activities here has certainly provided a fruitful avenue for considering alternative teaching strategies. Such a proposal has implications for curriculum development particularly as this may require the inclusion of greater scope for more hands on experiences. Previous research has highlighted the importance of practical work in science classrooms (Gott & Duggan, 1996; Wellington, 1998; Wickman & Ostman, 2002; Hogarth et al, 2005; Millar, 2010). However, research has also shown that in some cases practical work may not be effective if it is not sufficiently planned (Abrahams & Millar, 2008). That said it is also important to remember that some science teachers, particularly in primary schools, have difficulty coping with the subject matter and may lack the confidence to take a similar approach to tuition as was developed in this work (Ofsted, 2008; Boyle & Bragg, 2005; Ritchie, 1996; Holroyd & Harlen, 1996; Russell et al, 1995; Osborne & Simon, 1996; Russell et al, 1992).

## **8.5 A Multimodal Research Lens and Conceptual Change in Science Education**

In this thesis, a new and innovative multimodal, task-based approach to studying children ideas in science was presented. The work detailed in these chapters began by reviewing, evaluating and critiquing a substantial and influential body of research aimed at documenting how children's ideas across different science concepts develop and change over time and the various models of conceptual change arising. This work provided necessary background and context for the multimodal

perspective subsequently developed and to take this body of research forward. It was argued that multimodal research attends to different types of communication such as gesture when exploring children's ideas. Combined with more traditional approaches, findings point to a productive and insightful union at least as applied across the three age groups of children in the schools involved. There is no immediate reason to assume that the multimodal, task-based approach would not have more widespread value.

In addition to adopting a dialogic approach to teaching electricity and floating and sinking, and eliciting children's ideas, new methods or analytical tools were introduced including storyboarding, timeline diagrams and using NVivo to analyse and manage the data set obtained. Within the overall design and its limitations, these, it was argued and evidenced, proved effective, valid and reliable, particularly when considering instigating and capturing the dynamics of conceptual change. The gestures that the children produced during the tasks were categorised according to their content into a new typology. The prevalence of gesture types varied with age suggesting that sometimes children used them to support discussions when they found it difficult to articulate their ideas by other means. In addition to proposing a new typology of gesture in science education, findings were also used to capture the dynamics of conceptual change making an important contribution to theoretical perspectives and 'hybridity' in science education as a whole. It was proposed that the results from this study may have implications for classroom practice. Most notably, these implications support a view that there should perhaps be more opportunities for children to use a range of communication strategies when discussing their ideas in the classroom.

In response to the overarching research question raised it is argued that it is possible to apply a multimodal research lens to the issue of conceptual change in science education research. It is proposed that this approach provides a more holistic understanding of children's ideas and how they change both during the course of single teaching incidents and over time between age groups. Further research considering a multimodal lens applied to science education and the issue of conceptual change would appear to have merit, particularly with regard to exploring and testing the notion of 'hybridity' in cognitive models of conceptual change while

not forgetting the social and affective dimensions. Further work might be usefully directed towards exploring the application of a multimodal task-based approach with other age groups including, for example, GCSE, A-level and university students, trainee teachers and science educators in quasi-experimental, longitudinal and other studies.

Finally, in this thesis I have argued that an analysis of gesture alongside other response types supported by the multimodal research lens is important if both researchers and teachers are to have a holistic understanding of children's ideas in science. Gestures can illuminate aspects of knowledge that are not contained in any other response type, for example spoken and written language and drawings. Understanding the content of gestures can reduce the ambiguity that can be associated with those other response types and this approach is particularly helpful for understanding the ideas that children have if their language is under-developed. Furthermore, analysing gestures can reveal some of the processes associated with learning science concepts at a deeper level. In this thesis it has been argued that the analysis of gesture alongside the other responses types had great utility for exploring the predictions made by the four models of conceptual change studied in this work. Indeed it is proposed that this approach has facilitated those four models to be incorporated into a coherent framework that can be used to predict concept learning and development across a range of levels from fine to coarse grain. Gestures also offer a window of opportunity to explore the social aspects of learning in the classroom environment.

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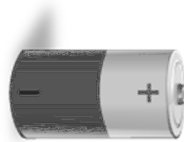
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## Appendix A – Worksheet for electricity

### Electricity

Complete this picture to make the bulb light



The bulb lights because.....

.....

.....

.....

## Appendix A – Worksheet for electricity

### Electricity

Complete the diagram to make the bulb light and label the symbols



The bulb lights because.....

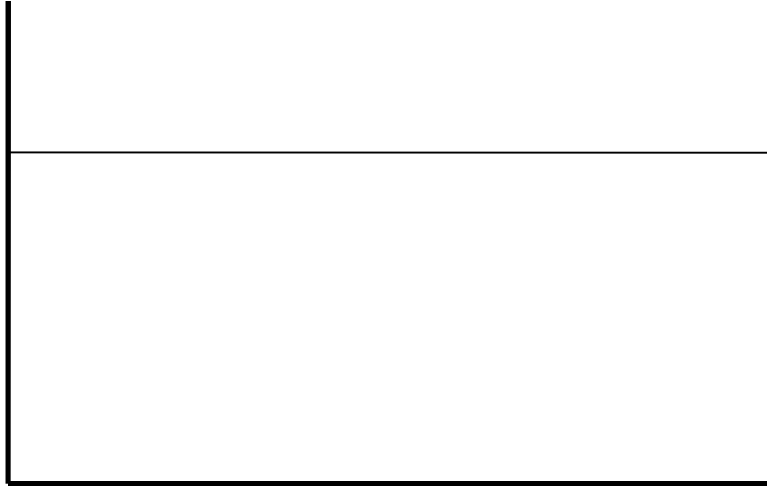
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## Appendix B – Worksheet for floating and sinking

### Floating and Sinking



Draw something floating and something sinking.

Things float because.....

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.....

Things sink because .....

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